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Highlights

- A new methodology to create the user's health profile has been defined and implemented by using dynamic adaptive questionnaires prepared by medical doctors. The resulting health profile extends the typical user profile of adaptive web system, by including information about health status and eventual chronic diseases provided by the user.
- A database of typical Calabrian foods compiled by nutrition specialists, where each food is annotated by nutritional facts and indication/counter indication with respect to main diseases.
- A recommendation methodology that suggests foods to the user according to his/her health conditions and eventual chronic diseases. The system adapts contents using a content selection approach.

DIETOS: a dietary recommender system for chronic diseases monitoring and management

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Abstract

Background and Objective: Use of mobile and web-based applications for diet and weight management is currently increasing. However, the impact of known apps on clinical outcomes is not well-characterized so far. Moreover, availability of food recommender systems providing high quality nutritional advices to both healthy and diet-related chronic diseases users is very limited. In addition, the potentiality of nutraceutical properties of typical regional foods for improving app utility has not been exerted to this end. We present DIETOS, a recommender system for the adaptive delivery of nutrition contents to improve the quality of life of both healthy subjects and patients with diet-related chronic diseases. DIETOS provides highly specialized nutritional advices in different health conditions.

Methods: DIETOS was projected to provide users with health profile and individual nutritional recommendation. Health profiling was based on user answers to dynamic real-time medical questionnaires. Furthermore, DIETOS contains catalogs of typical foods from Calabria, a southern Italian region. Several

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Calabrian foods have been inserted because of their nutraceutical properties widely reported in several quality studies. DIETOS includes some well known methods for user profiling (overlay profiling) and content adaptation (content selection) coming from general purpose adaptive web systems.

Results: DIETOS has been validated for usability for both patients and specialists and for assessing the correctness of the profiling and recommendation, by enrolling 20 chronic kidney disease (CKD) patients at the Department of Nephrology and Dialysis, University Hospital, Catanzaro (Italy) and 20 age-matched healthy controls. Recruited subjects were invited to register to DIETOS and answer to medical questions to determine their health status. Based on our results, DIETOS has high specificity and sensitivity, allowing to determine a medical-controlled user's health profile and to perform a fine-grained recommendation that is better adapted to each user health status. The current version of DIETOS, available online at http://www.easyanalysis.it/dietos is not intended to be used by general users, but only for review purpose.

Conclusions: DIETOS is a novel food recommender system for healthy people and individuals affected by diet-related chronic diseases. The proposed system builds a users health profile and, accordingly, provides individualized nutritional recommendations, also with attention to food geographical origin.

Keywords: food recommender system, health profile, foods database, chronic diseases, chronic kidney diseases.

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1. Introduction

The positive correlation between obesity and cardiovascular mortality, all-cause mortality, and the risk of cardio-metabolic diseases has been widely reported and is a diagnostic variable for metabolic syndrome. Diet-related diseases are, consequently, the most common cause of death worldwide and are associated with an excessive sature fat acids, animal proteins and/or free sugars intake [1, 2, 3, 4, 5, 6].

A prototype of diet-related disease associated with high cardiovascular morbidity and mortality is chronic kidney disease (CKD) [7, 8, 9, 10]. CKD is characterized by a progressive and irreversible loss of kidney function that, however, is accompanied by blurred symptoms until the hypertrophic residue renal tissue fails to deliver the clinical compensation [11]. The main determinants of CKD and its progression are hypertension and diabetes, themselves clinically silent [11].

The unawareness of being hypertensive, or diabetic or affected by CKD represents the main obstacle to interfere the progression of renal damage and to prevent the occurrence of its complications [12]. Therapeutic diet regimens have been individualized for different disease stages according to Kidney Disease Outcomes Quality Initiative (KDOQI) guidelines [13]. The clinical profiling represents a fundamental tool for a correct management of the diet in this typology of patients while the monitoring of clinical responses and compliance to the prescription is the major mission of nephrologists and nephrology-dedicated nutritionists.

New communication technologies could benefit the collection of food intake data and, generally, dietary monitoring and diet-related chronic diseases management. In [14], authors highlighted how text messages, smartphone apps, and web-based programs could have positive impacts on users behaviors. There is a wide proliferation of nutrition related web and mobile applications, but further research is necessary to assess the effectiveness of apps for weight and diet management [15, 16], that lack of evidence-based contents. Moreover, computer vision, video games, wearables and augmented and virtual reality appear potentially useful to support dietary and weight monitoring [17]. However, at the best of our knowledge, none of available systems combine together health profiling, specialized dietary advices with attention to food geographical origin, clinical and compliance monitoring in users affected by chronic diseases. Despite few research projects have presented food recommender systems (RS) addressed to diabetic or CKD users, they missed to consider all aspects necessary for a correct dietary and clinical management.

In this paper, we present the optimized architecture and functionalities of a web-based Recommender System (RS) called DIETOS (DIET-Organizer System). In two previous papers [18, 19], we presented early versions of DIETOS. Current DIETOS form contains several innovative aspects:

- The methodology provides individualized nutritional recommendations according to user health profile obtained through the administration of medical questionnaires provided by nutrition specialists and nephrologists and accomplishing to World Health Organization and KDOQI guidelines.
- The ability to profile not only healthy users but also patients affected by CKD, hypertension and/or diabetes. Furthermore, CKD users are provided with glomerular filtration rate estimation by Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) formula for disease staging.
- To the best of our knowledge, DIETOS is the first RS containing a catalog of typical regional foods characterized by nutraceutical properties. Also, the system is modular, and the food database can be promptly extended with new products. As strength point, based on his/her health profile, DIETOS provides user with Calabrian typical foods benefits and side effects.
- Conversely to conventional RSs in which user health profiling is based only on a generic behaviour data entry by the user, in DIETOS a high quality health profiling is achieved because the user has to provide several clinical measurements (e.g., creatinine, blood glucose, blood pressure).

The paper is organized as follows: in Section 2 we describe the state of the art related to existing web systems and mobile apps for dietary monitoring and management. In Section 3, a detailed description of DIETOS architecture and functionalities is reported. In Section 4, is outlined a pilot study conducted on a cohort of CKD patients and healthy subjects and it presents the experimental results in terms of collected variables and systems calculated performance parameters. Section 5 discusses the DIETOS results and compares the systems features to similar systems, highlighting advantages and innovative aspects of our system. Section 6, finally, draws the future work planning and conclusions.

2. Related work

Nowadays there is a widespread diffusion of web and mobile applications (apps) for weight and diet management. These applications help users to choose for healthy food, log his/her nutrition intake and pick and choose a healthy diet plan. Many of these systems provide information about macronutrients and micronutrients. Others have been designed to help users to find recipes that reduce health risks and food sensitivities, create grocery lists, and engage in other aspects of the meal plan. Moreover, novel RSs include video games, wearables, and augmented and virtual reality that demonstrate potential to support dietary and weight monitoring. In [20], authors propose a goal-based slow-casual game approach that addresses the need for an intervention that educates the public on how to make healthy choices while eating away from home. u-BabSang [21] is a RS that provides individualized diet advices in real time, while the user is at the dining table.

Even though mobile and web-based applications for weight and diet management are increasinly used, the quality of these apps remain not well-characterized [22, 23]. They are not usually experimented in clinical contexts, as well as they are not supported by medical evidence, and most of them do not include the behavior change techniques (BCTs) [24, 25].

Moreover, as pointed out by [26], the general focus of these systems is on weight loss and calories counting. Personalized nutrition recommendations are quite limited, and they do not take into account the quality of foods consumed.

An interesting comprehensive review is [27]. Authors analyze quality and BCTs of popular weight management apps available on both iTunes and Google Play. App quality was measured through the MARS scale [28] that explores engagement, functionality, aesthetics and information reliability. Overall, popular apps showed moderate quality, but scored higher in terms of functionality and aesthetics. Self-monitoring and provision of feedback were the BCTs most frequently identified in different apps. Similarly to other reviews, authors stated that apps generally lack of experimental validation.

In [29], authors evaluated feasibility and short-term efficacy of a mobile phone app in the prevention of diabetes onset in overweight English-speaking adults. The mobile app included electronic diaries for weight, physical activity and calories intake self-monitoring, supported by daily reminders to enter data and providing weight loss as a primary outcome. Text messaging and mobile apps were therefore found to be promising tools for delivering weight loss interventions and achieving clinically significant weight loss in overweight adults.

Conversely, another systematic review aiming to investigate the benefits of dietary mobile apps in dietary intake and clinical outcomes in the renal population, has been presented in [30]. Of 712 studies considered, only five were eligible for inclusion in the review and only two were randomized controlled trials (RTCs). Based on their literature analysis, authors concluded that the use of dietary mobile apps does not allow to reveal notable changes in nutrient intake, biochemical markers or weight gain. Furtermore, the need for additional rigorous trials with larger sample sizes to determine the effectiveness of dietary mobile app intervention was highlighted. Also, authors recommended the use of high-quality apps preferably including advices on local foods.

Moreover, at the state of our knowledge, these apps do not are devoted to users affected by diet-related chronic diseases, such as hypertension, diabetes or CKD. In literature, few dietary systems dedicated to chronic diseases are proposed as research projects.

A pilot CKD dietary consultation system by constructing an OWL-based (Ontology Web Language) knowledge base system (KBS) was presented in [31]. The system to perform diet consultation is based on the entering of personal data and the clinical diet suggested key nutrient intakes. The system outcomes include the evaluation of patients' CKD clinical stage, suggested food servings and suggested key nutrient intake.

In [32] the authors presented a web application called PREFer (Prescription for REcommending Food) for food recommendation. Relevant recipes are selected by content-based retrieval, based on comparisons among features used to annotate both users profile and recipe. The recipes are also ranked according to the medical reference prescription schemes (i.e. a proper combination of recipes that are advisable for specific kind of users).

In [33], the authors have implemented a new system that allows users to balance their tastes and health. Their recommender system not only offers recipe recommendations that suit the user's preference but is also able to take the user's health into account. The described demo system has been developed on the Android platform.

Another web-based food recommender system is in [34]. The authors use some personalization techniques to propose a semantic framework for food recommendation based on the user's preferences, the health condition of the user and the culture influence on the food choice.

A main limitation of these last systems devoted to users affected by diet-related chronic diseases is the fact that personalization and adaptation is mainly focused on user preferences and not on health status and medical variables as in DIETOS. A precise diagnosis and staging of the disease is essential to personalize dietary advices. Indeed, availability of measured data, such as lab tests, helps doctors to improve patients management. Consequently, RSs might represent useful medical tools for clinical data collection and analysis to provide users with personalized high quality advices [35, 36].

3. DIETOS: DIET Organizer System

DIETOS (DIET Organizer System) is a web-based RS that automatically provides users with health profiles including CKD, diabetes and hypertension status. In addition, based on user health profile, DIETOS provides individualized nutritional recommendations, also considering nutraceutical characteristics of the typical Calabrian foods. In order to define user health profile, DIETOS submits to the user a series of medical questions requiring the entry of different laboratory and vital parameters. User health profile is built by analyzing the answers given time to time by the user as well as, providing dynamically the next question for the user. The methodologies implemented in DIETOS make possible to obtain very accurate users' health profile that matches with the diagnosis made by the doctors.

3.1. Architecture and main functions

In this section, we describe the architecture and main functions of DIETOS. The DIETOS architecture is depicted in Figure 1 pointing out the main modules, that are: *DIETOSUserProfiler*, *DIETOSReminder*, *DIETOSHistory*, *CKDCalculator*, *DIETOSFoodsFilter* and *DIETOSSecurity*. Moreover, the DIETOS Database contains several data tables about user profile, foods, pathologies, questionnaire, that are accessible by the software modules described below.

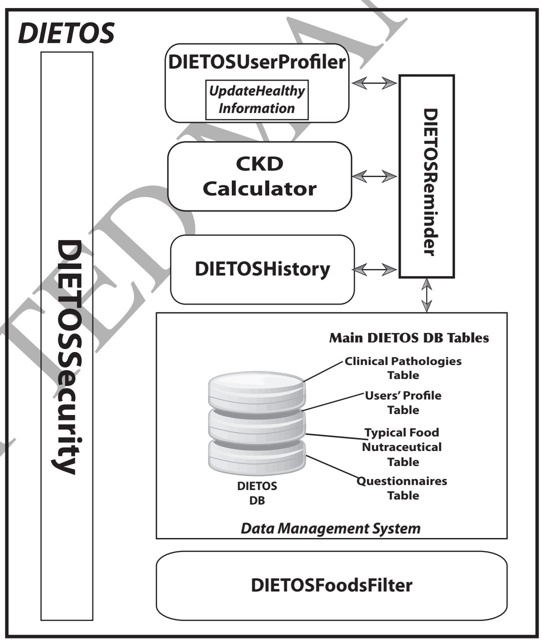

Figure 1: **DIETOS Architecture.**

DIETOSUserProfiler by giving specific questions about clinical parameters (i.e. blood pressure, blood glucose and so on) to the users, can infer the user's health status. A set of questions used to profile a specific pathology is called questionnaire. Questionnaires are modelled by using a tree, where nodes are the questions while an edge connects two nodes related to them by a particular value (answer) to the current question. This strategy makes DIETOS scalable and efficient during the user health profiling step. Questionnaires are adaptive, that is, the next question to submit to the user is obtained by analyzing the child's node of the current node of the profilation tree. This solution allows conveying to the users only relevant questions related to their real health status, making it possible to define the health profile accurately. Thus, the system gives to the user more accurate alimentary advice, related to his/her health status, avoiding to provide unsuitable advice. It is worthy to note that, the system described so far has the potential to provide alimentary advice only whether users are willing to answer the questions submitted. The questions to provide to the users are built upon the profiling methods provided by the medical team, as well as composing the results of querying the database that contains the information related to the pathologies.

DIETOSHistory saves all changes made by the user so that the data can be used to monitor the user's health status. DIETOS through the *DIETOSReminder* module can detect possible incongruence related with the newly entered values and the stored data. In the case that the entered values are probably incorrect, the system points out the potential incongruence to the user that can decide to revise or not the entered value. In this way, the system taking into account the user's history can suggest the most suitable foods, about his/her up to date state of health, as well as can provide to the users an automatic assisted procedure to manage his/her personal profile.

The *CKD calculator* is the sub-module that calculates the Glomerular Filtration Rate (GFR) parameter that is used to evaluate kidney functionalities, according to the CKD-EPI formula. The computation of this parameter is needed to profile correctly CKD users. The detailed explanation of the parameter and used formula will be described in subsection *User's health status profiling methodology.*

The *DIETOSFoodsFilter* can advise from the food list submitted by the user, the foods compatible with his/her health status, that can be eaten without side effect. The food selection is performed through a well known adaptation strategy of adaptive web systems called "content selection". The results are conveyed to the users in a graphical format, specifying the correct quantity of each food that can be eaten daily, furthermore, advising alternative foods that can help tackle the health problems.

Among the different functions performed by DIETOS, there is the periodically reminds function, that signals to the user that maybe it is time to update his/her profile for example if a long time has elapsed since the last change. DIETOS (through the *UpdateHealthInformation* sub-module) signals to the user that is passed a long time from the last update, regarding specific characteristics (i.e. for a diabetic subject the primary parameter to monitor is the blood glucose GL). Updating some significant user's features, for example, GL, the system can estimate the best food with the actual health status of the user, as well as automatically report to the user all related constraints that need to be updated.

Finally, the data stored in the DIETOS database are sensible information for which it is expected an adequate protection, both during the transmission process that storage. At the moment of writing the secure data transfer is under development. The data stored in the database are protected, encrypting the database. Database encryption is the process of obfuscate data stored in a database, by converting plain text format into a meaningless cipher text using a suitable algorithm, protecting in this way the sensible stored data.

3.2. DIETOS methodologies

The adaptive part of the recommender system uses well-known techniques for user profilation and content adaptation. In adaptive web systems [37, 38], information for building user profile can be gathered by observing users, thus adopting the Automatic User Modeling (or Implicit Acquisition), or allowing users to directly intervene in the process of modeling, through content rating, questionnaires, and explicit data provision, thus adopting the Cooperative User Modeling (or Explicit Acquisition). Regarding user profilation, as explained in detail in the following subsections, DIETOS uses the Cooperative User Modeling. In particular, the information gathered through the questionnaires is used to build a so called overlay user profile, described through a set of attribute-value pairs. Regarding content adaptation, we refer to the techniques used to adapt the content showed to the user on the basis of his/her profile. One of the most used content adaptation strategy is named content selection. In content selection, the web pages and, in particular, the elementary content data (e.g., the items in a catalogue) are characterized by features (e.g., colors, price, etc.) and the specific contents showed to the user are selected from all the items in the catalogue by matching user profile (e.g. if the user likes items with low price, only items with low price are chosen). DIETOS uses the content selection adaptation strategy. In particular, when the system has to show foods to the user, among all the foods present in the database, it selects only the foods that have the attribute "recommended" and "use moderately" for the specific disease/health profile of the user. Moreover, the showed foods are ranked on the basis of the previous attributes.

3.2.1. User's health status profiling methodology

DIETOS dynamically builds a health profile for the user, necessary to determine which typical Calabrian foods are compatible or not with the user's health condition. The acquisition of the health profile is based on a simple, unidirectional and comprehensive set of questions called questionnaire, provided by the medical specialists that would categorize the screened subject as a diabetic, a hypertensive or a CKD patient. User profiling in DIETOS is done through the implementation of the guidelines used by doctors during the clinical investigation procedures. Guidelines are provided by the doctors in form of flow-chart (let see Figures 2, 3 and 4). Further, flow-charts are implemented in DIETOS as questionnaires. It should be noted that the questionnaires employed in DIETOS are original, thus they cannot be found in the literature. In fact, although they are based on the international guidelines, flow-charts and related questionnaires were designed by medical specialists in our group. Questionnaires are represented in DIETOS as a tree whose nodes are all the questions used in the guidelines, whereas the edge connecting two nodes represents the answers.

Some parameters such as the value of blood-glucose and blood-pressure make it possible to detect the diabetes or hypertension if they are above a given threshold. For example, the main steps of the flow-chart reported in Figure2 are described in the following. First of all, it is investigated if the user takes the pill for diabetes or he/she assumes insulin. If the answer is positive, the user is classified as diabetic; otherwise he/she is asked to enter the glycemic value, and if this value is greater than 100 mg/dl, other checks on the same measure are required to avoid eventual errors. If the user confirms all times that the glycemic value is greater than a specific threshold of 126 mg/dl, then he/she is classified as diabetic. If the glycemic value is, instead, in the range of 110 mg/dl and 126 mg/dl, the user has a low sugar tolerance otherwise he/she is not diabetic. Instead, to evaluate the kidney functionality it is mandatory to use the CKD-EPI formula to compute GFR, Glomerular Filtration Rate (see Equation 1). The GFR is a value used to determine the subject's stage of kidney disease (see Table1).

Table 1: The five stages of CKD and GFR for each stage

Stages CKD		**GFR value**
Stage 1	Normal	GFR >90 mL/min
Stage 2	Mild CKD	60-89 mL/min
Stage 3A	Moderate CKD	45-59 mL/min
Stage 3B	Moderate CKD	30-44 mL/min
Stage 4	Severe CKD	15-29 mL/min
Stage 5	End Stage CKD	GFR <15 mL/min

The formula to compute eGFR (estimated GFR) value is the following:

$$eGFR = 141 \times min\left(\frac{SCr}{K,1}\right)^{a} \times max\left(\frac{SCr}{K,1}\right)^{-1.209} \times 0.993^{Age} \times [b] \qquad (1)$$

Where:

$$\mathbf{b} = \begin{cases} 1.018 & \text{if} \quad \text{Female} \\ 1.159 & \text{if} \quad \text{Black} \\ 1.0 & \quad\quad \text{Otherwise} \end{cases}$$

In Equation 1 SCr refers to the serum creatinine expressed in *(mg/dL)*, K is equals to 0.7 for women and 0.9 for men, a is equals to -0.329 for women and -0.411 for men, min is the minimum of SCr/K, and max is the maximum of SCr/K.

The user having a CKD profile should be further categorized as CKD on conservative therapy or CKD on dialysis, as these two conditions involve different therapeutic and dietary approaches by KDOQI guidelines [13]. This profiling includes the automatic extension of the questionnaire for the acquisition of anthropometrics and creatinine values for the computing of automated estimated GFR (eGFR) with CKD-EPI equation [39] for a correct staging of CKD according to KDOQI CKD classification [40] as depicted in Figure 4. The positive impact of targeted dietary therapy based on scientifically validated guidelines has been tested for all diabetes, hypertension and all CKD stage [41, 42, 43]. Also, for all these diseases the use of certain foods can be strongly contraindicated. The approach used in DIETOS to infer the user health status consists, in posing a series of questions about the characteristics of the diseases. Each time DIETOS receives an answer, a follow-up question is asked until it reaches a conclusion about the type of the disease. The set of questions and the possible answers can be represented in the form of a profilation tree. A profilation tree is a hierarchical structure consisting of nodes and directed edges. Specifically, in a profilation tree, to each leaf node is assigned a healthy or disease label to infer the user's health status. Instead, the intermediate nodes, contain the test

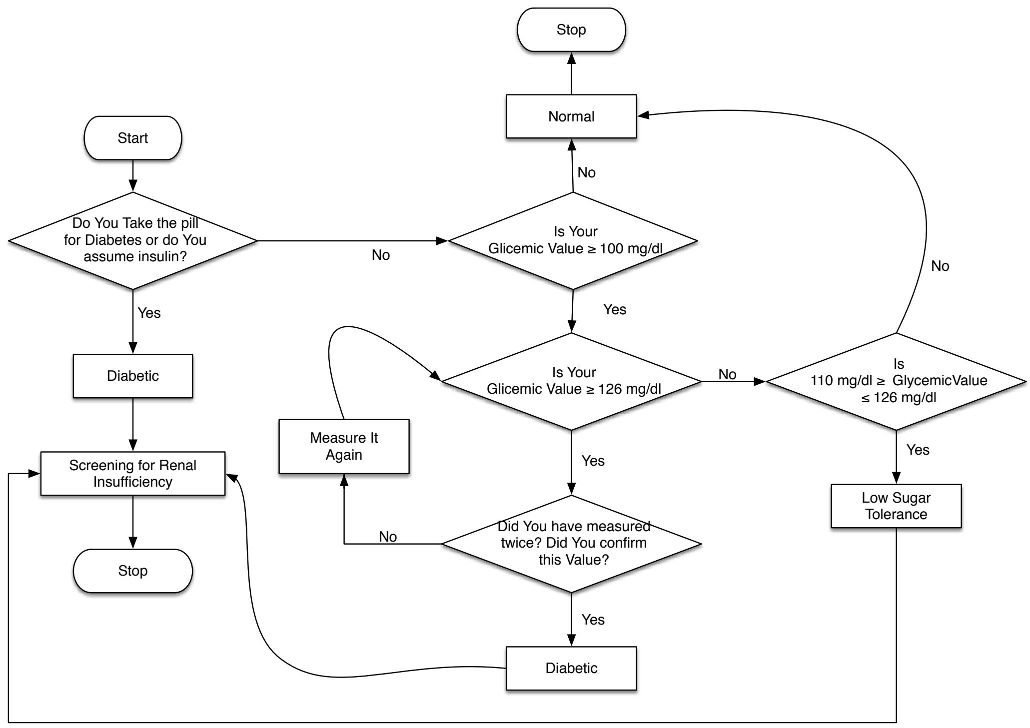

Figure 2: Flow chart used to profile a diabetic user.

305 condition values, to separate answers that have different properties. A question tree can be built by implementing the flow charts described in the previous section. In the flowcharts, each step contains the necessary information to create the questions to give to the user, to figure out whether the user is healthy or not. The initial tree for the profilation problem contains a single node the root
310 node (corresponding to the start node of the flowchart). The root node is a particular node with only outgoing edges and does not has incoming edges. The other nodes to add to the tree are the steps composing the flowchart, that are

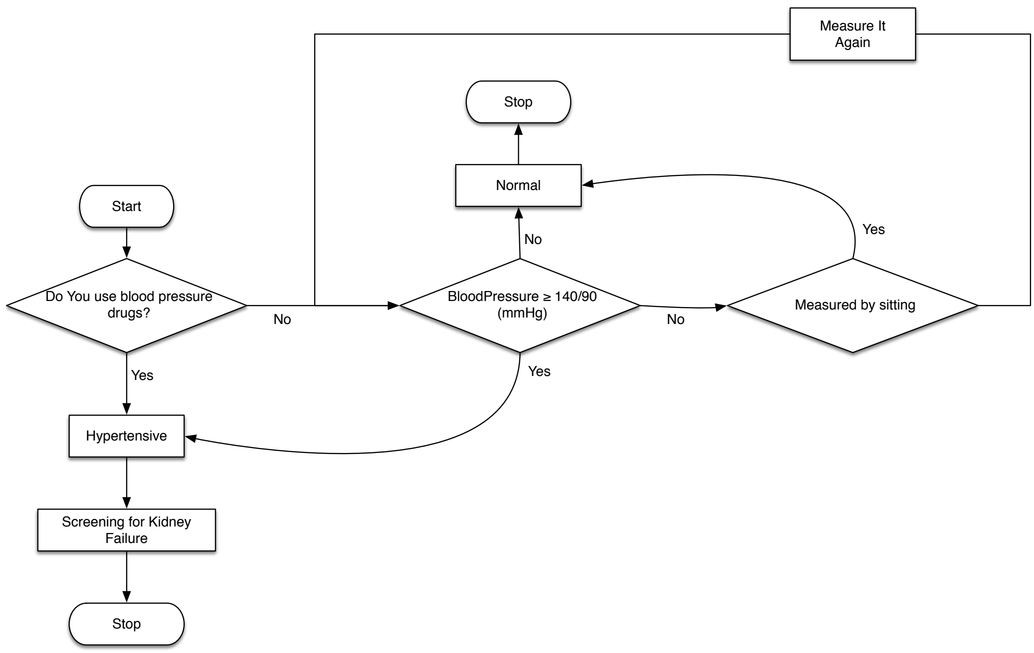

Figure 3: Flow chart used to profile a Hypertensive user.

subsequently divided into smaller sub-steps based on the outcomes of the test condition. DIETOS' profiling algorithm is then applied recursively to each sub-step of the root node until all the steps belonging to the flowchart are analyzed. Algorithm 1 describes the main steps used from DIETOS to create the profilation tree. To illustrate how the DIETOS' profiling algorithm works, let consider the problem of predicting whether a user is affected by CKD. To figure out if a user is affected by CKD, the first question that DIETOS may ask to the user is the Creatinine value to compute eGFR. If the entered eGFR value is greater than (80 ml/min), the user should not follow dietary restriction. Differently, if the eGFR value is greater than 20 ml/min user should follow a low protein low salt and hypophosphate diet. Otherwise, eGFR value less than 20 ml/min user

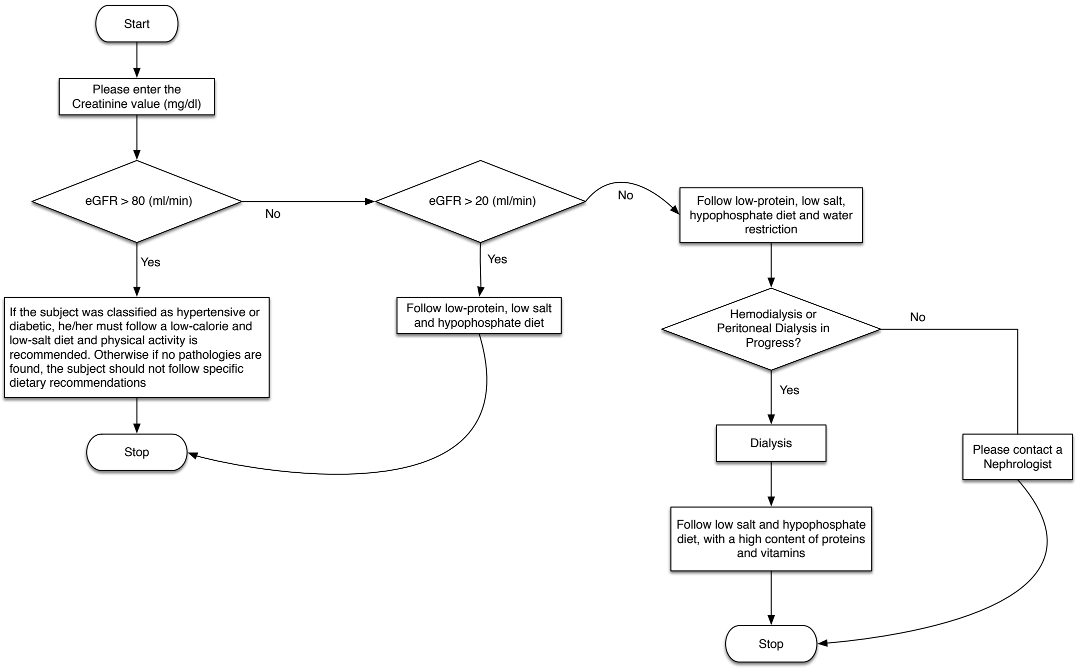

Figure 4: Flow chart used to profile a kidney user. This chart follows hypertensive and diabetics charts. Thus the results of the left branch of this chart depends on the profile obtained by using the previous charts.

should follow a low protein low salt and hypophosphate diet and should contact a nephrologist, if he/she is not under dialysis. The previous example illustrates how DIETOS can solve a profilation problem by asking a series of questions about the attributes of the disease. Thus, the creation of a full questionnaire requires to scan only a single path of the tree, and the path-choice is driven by the answer given by the user time by time. To find all the n questions to profile a user, DIETOS has to scan at most n nodes and perform a driven-search on the list of children for every node depending on the current answer. Algorithm

2 describes the methodology implemented in DIETOS to profile user' health status.

The use of flow charts is mandatory because they allow to estimate accurately and highlight particular conditions that affect the user's health status. Moreover, the flow charts make it possible to obtain the information necessary to create a simple patient health record. Patient's health information are stored in a dedicated patient health record. Medical records need to include: the patient's contact and demographic information, clinical and laboratory data/treatments and so on. Besides clinical information, the patient health record contains other fine grain relevant information such as blood pressure, blood glucose, eGFR to monitor more in detail and accurately the user's health status.

Table 2: Some examples of typical Calabrian foods (quantity 100 g) stored in database with relative nutritional facts

Food	**Nutrients**			
	Calories(kcal)	Protein(g)	Fats(g)	Carbohydrates(g)
Cipolla rossa di Tropea	26	1	0.1	83
Caciocavallo silano	439	37.7	31.1	2.3
Capocollo	450	20.8	40.2	1.4
Patata	77	2.02	0.09	17.46

3.2.2. Food recommendation methodology

After the user has been profiled, the system recommends what typical foods can be consumed by the user. In this section, we describe some of the core approaches and specific algorithms that DIETOS uses to advise foods to the users. DIETOS gives to the users information on typical Calabrian foods through three different way: *i)* by automatically suggesting foods according to the user's health profile; *ii)* by displaying on a map the locality where the Calabrian foods are produced; finally *iii)* by showing the nutritional properties for each food stored in the database, including benefits and side effects on pathologies and specific health conditions. For example, Table 2 conveys the characteristics of some of

```
Data: Medical Guidelines Questionnaires
Result: Profile Tree
Tree t = 0;
Let ℧ = {The Questionnaires set};
buildTree(Node n){
if (!∃ root) then
    root = createNode();
else
    if (stopCond == true) then
        n = createNode();
        n.addValue();
        addNode(n);
        return n;
    else
        foreach step ∈ ℧ do
            Δ = findSplit(step);
            let Δ = {δ|δ ∈ step};
            foreach δ ∈ Δ do
                buildTree(δ)
            end
        end
    end
    return t;
end
```

Algorithm 1: DIETOS algorithm to build profilation Tree. The main steps of the profilation tree are: creation of the root node, at which are added the other nodes the steps composing the flowchart. Each step is subsequently splitted into smaller sub-steps based on the outcomes of the test condition. The algorithm is applied recursively to each sub-step of the root node until all the steps belonging to the flowchart are added to the tree.

Data: User Answer s

Result: User health profile Φ

`visit(`*Node n*`)`

foreach *node* $\nu \in t.Adj\{u\}$ **do**

  if $\nu \equiv$ *getUserAnswer()* **then**

    Φ.add(ν);

    visit(t,ν);

  end

  ν.markVisited();

end

Algorithm 2: DIETOS profilation Tree traverse algorithm to figure out the user's health status.

the typical foods while Table 4 shows the beneficial effects of the foods and the categories for which the typical product is recommended, should be used moderately or not recommended.

To give users advice, DIETOS uses health status data of the profiled user, diseases data, and foods data. In particular, the DIETOS *FoodFilter* (see Figure 1) uses health-based, diseases-based, foods-based information to advise users. The traditional recommender systems used in e-commerce are based on collaborative filters to infer the users' preferences. Thus, to be able to make a recommendation in a population, it is necessary to classify the users by using navigation data, behavior data, preferences data using data mining or statistical algorithms. Conversely, in DIETOS there is no need to use statistical or data mining algorithms to classify users, because the system implicitly classifies users during the profiling step, according to their health status. Algorithm 3 describes the primary steps of *DIETOSFoodsFilter*.

```
Data: logged in user health profile, foodsCatalog and diseasesCatalog
Result: Visualization of the list of suitable/improper foods, respect to
        the user's health profile
List suitableFoods = 0, improperFoods = 0;
if (is_user_logged_in()) then
    User u = loggedUser.BuildHealthStatus();
    foreach Food f in TypicalProductCatalog do
        if (f.isCompatible(u.healthStatus())) then
            suitableFoods.add(f);
        else
            improperFoods.add(f);
        end
    end
    orderList(suitableFoods) ;  /* order the foods according to how
    much appropriate they are */
    orderList(improperFoods) ; /* order the foods according to how
    less appropriate they are */
    VisualizeIn2UserHome(suitableFoods, improperFoods) ;     /* will
    convey to the user the ordered foods */
else
    throw Unknown_User_Error_Exception;
end
```

Algorithm 3: Visualization of the lists of suitable/improper foods, with respect to the user's health profile. The lists of suitable/improper foods are conveyed to the user by qualitatively ranking them according to how much appropriate they are or how less appropriate they are.

Table 3: Nutritional facts for 100 g of Tropea's red onion. Data obtained from the Italian Data Bank "Consiglio per la Ricerca in Agricoltura e l'analisi dell'economia agraria" CREA

COMPONENT	MEASURE	QUANTITY
MAIN		
Calories	kcal	26
Calories	kJ	110
Lipid	g	0.1
Carbohydrates	g	83
Protein	g	1.0
Water	g	92.1
Fibers	g	1.1
MINERALS		
Calcium	mg	25
Phosphorus	mg	35
Iron	mg	0.40
Potassium	mg	140
Sodium	mg	10
VITAMINS		
Retinol (A)	mg	3.0
Thiamine (B1)	mg	0.02
Riboflavin (B2)	mg	0.03
Niacin (B3)	mg	0.50
Ascorbic Acid (C)	mg	5.0

Table 4: Beneficial effects of the red onion of Tropea and the categories for which it is recommended, should be used moderately or not recommended, according to the clinical studies reported in the literature.

BENEFICIAL EFFECTS	RECOMMENDED	NOT RECOMMENDED USE MODERATELY
Hypoglycemic [44]	Diabetes [44]	Gastritis
Hypolipidemic [45]	Hypertension [46]	Gastro-Duodenal Ulcer
Antioxidant [47]	Cardio-Vascular Diseases	
Adjust the intestinal flora	Stipsi	
Diuretic effect	Dyslipidemias [45]	
Laxative effect		
Digestive effect		

3.2.3. DIETOS Database

The food information and user data contained in DIETOS are archived into a MySQL database.

The principal tables composing the database are: ***Clinical Pathologies related Table*****,** ***Users Profile related Table*****,** ***Typical Food Nutraceutical related Table*****, and** ***Questionnaires related Table***.

- *Clinical Pathologies related Table* stores pathologies identified by using the International Classification of Diseases [1], 9th Revision, Clinical Modification (ICD9-CM) along with a description of the stored disease. Using ICD9-CM as identifier makes it possible to uniquely identify pathologies among all users around the world.
- *Users Profile related Table* stores all the personal and health information of the user. Even *Users Profile related Table* is modeled using the master-slave table model [48] for two reasons, to make easy to update the user health status as well as to manage the user's history efficiently, that is

[1] http://www.cdc.gov/nchs/icd/icd9cm.htm

useful to provide advice and statistical reports.

- *Typical Food Nutraceutical related Table* contains extensive information on many typical Calabrian foods while the nutraceutical properties, proteins, amino-acids, vitamins, that differ from food to food are stored in several tables following the master-slave table model. In this way, it is simple to add new foods with new nutraceutical properties as well as avoiding to create redundant data and wasting space. The database stores the Calabrian foods classified as Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI). Tables 2 and 3 contain some examples of included foods with relative nutrients.

- *Questionnaires related Table* has been designed to store several different types of questionnaires provided by the medical group, which are used by DIETOS to figure out the health of each profiled user. In details, the database has been developed to store heterogeneous data such as the questions and the answers record. To make efficient the creation of the Profilation-Tree, we developed a principal question table to store the question definitions, organized into categories, whereas the answer table stores the critical clinical information (i.e. blood-glucose, blood-pressure and so on) necessary for the system to figure out the user's health status.

Briefly, the database is developed and implemented for systematic analysis of users' health status and foods, linking personal health information with typical nutraceutical properties of Calabrian foods.

3.3. DIETOS System

All the information stored in the database are accessible to the user through a user-friendly web-based interface. In particular, the graphical interface is written in HTML5, CSS, and JQuery, whereas the server sides of DIETOS data querying and presentation are written by using the PHP (5.5.31 version) language (let see Figure 5). Information are archived into a MariaDB Server

10.1.19, developed by the original developer of MySQL with the aims to guarantee the open source nature of the database. The core algorithms and data structures of DIETOS are implemented by using PHP (version 5.5.31). The main advantages to use PHP is that, it runs on various platforms (Windows, Linux, Unix, Mac OS X) and it is compatible with almost all server like (Apache, IIS), as well as makes it possible to execute the user's call server-side efficiently and independently from the user web-browser. The web architecture of DIETOS is conveyed in Figure 6. The DIETOS system is freely available after registration at the following web-address: `http://www.easyanalysis.it/dietos`.

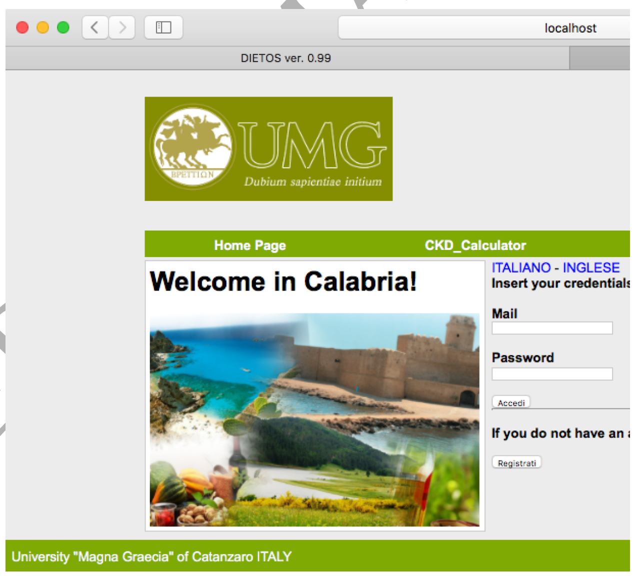

Figure 5: DIETOS home page.

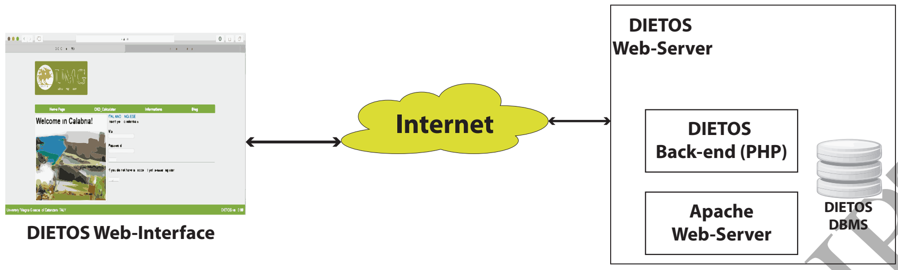

Figure 6: DIETOS Web architecture.

4. Experimental Results

In order to validate the correctness of the DIETOS profiling function and the usability, 40 **subjects** (20 normal and 20 affected by chronic diseases) were enrolled by the specialists by the Unit of Nephrology and Dialysis, Mater Domini University Hospital, Catanzaro, Italy. All subjects unable to use a computer and/or having any neurological or psycological impairment were excluded. 20 patients affected by chronic diseases were asked to sign an informed consent in accomplishment to Helsinki Declaration and were invited to register to DIETOS system. Patients data were evaluated by the nephrologist that provided the correct diagnosis. All patients were then invited to complete the profiling procedure of DIETOS system.

An analogue procedure was followed for healthy controls. 20 volunteers were preliminarily visited by the same nephrologist involved in patients diagnosis assessment, after they consented to participate to the study. Subjects without lab tests performed, underwent a blood withdrawal for creatinine and glucose determination. Blood pressure was measured. All subjects were asked to register to DIETOS and answer all questions of profiling procedure.

Table 5 summarises the main data entered by the users in DIETOS, that are the value of Creatinine measured respectively at the first contact, after 2 months and after 3 months, Blood-Glucose detected at the first contact, after 1 months and after 3 months, sex, age, weight, blood pressure and race. This set of features are enough to allow DIETOS to determine the health status of each user.

A nephrologist evaluated the output of DIETOS profiling methodology for all enrolled subjects. Table 6 reports experimental results. Specifically, true positive (TP) results are related to the output of DIETOS profiling that matches to specialist's diagnosis; true negative (TN) if the system found user that do not have the disease, false positive (FP) users not affected by diseases for which the system classified them as "sicked" and finally false negative (FN), i.e. diseased users but classified as healthy.

Using the data in Table 6 we computed the sensitivity and specificity reached by DIETOS to profile users' health status by using Formula 2 and 3.

$$Sensitivity = \frac{\#\text{ of True Positive}}{\#\text{ of True Positive} + \#\text{ of False Negative}} \tag{2}$$

$$Specificity = \frac{\#\text{ of True Negative}}{\#\text{ of True Negative} + \#\text{ of False Positive}} \tag{3}$$

The value of specificity is equals to 100% and represents the ability of DIETOS to profile user without the disease, while the sensitivity is equals to 91% and indicates the capability of DIETOS to profile users affected by the disease.

5. Discussion

The high values of specificity and sensitivity reached by DIETOS to profile healthy users and those affected by diet-related chronic diseases determine a reliable classification and a correct implementation of the health profiling.

According to the methodologies implemented in DIETOS and described in the previous paragraphs, DIETOS can suggest the best food according to the current health status of each profiled user. In fact, DIETOS, referring to the nutraceutical facts stored in the database, can retrieve and advice to the users the foods with the best nutraceutical properties for them and, at the same time, discourages the eating of foods with negative side effects on their health status. In particular, compliance to the diet in CKD patients, and, for all diet-related chronic diseases, is an important issue due to the use of expensive aproteic food that needs time for separate cooking of meals, ending in poor palatability, monotony and lifestyle change for the patient and its entourage. A close monitoring of diet efficacy and safety is also strongly needed for the modulation of the dietary regimen in response to the lab tests trend and the individual nutritional request. In this perspective, such personalization of the nutritional therapy is time demanding and involves relevant management problems for nephrologists and dietists. Therefore, a fully automated system able to modulate the dietary prescription, in real time, on receipt of the patient's clinical and laboratory data is desirable.

As presented in Section 2, some research prototypes have been proposed in the literature in the last years. Table 7 summarizes the main features of the proposed system in literature and our system. Some of them, such as [32] and [33], take into account information relative to health status in building user profiling and food recommendation tasks. Foods and/or recipes are not suggested only in according to user preferences or rating. The system presented by Chi et al. [31] has been designed specifically for CKD users. DIETOS includes not only CKD user categories but also diabetic and hypertensive. Moreover, the systems presented in [32] and [33] have not been fully clinically validated yet. Therefore, the few available diet management systems are intended for general use only. Instead, DIETOS is a professional diet management system for patients with specific health profiles and has been specially developed and dedicated to the diet and clinical management of CKD, hypertensive and diabetic patients. DIETOS is prone to professional use as its development and design are based on international guidelines for the management of patients with diet-related chronic diseases. In addition, DIETOS was subjected to clinical experimentation showing high specificity and sensitivity. To the best of our knowledge, current software systems used by nephrologists do not offer similar functions to those offered by DIETOS.

Table 5: The values entered by each single user necessary for DIETOS to create a health profile. In the table A is the age of the user, S refers to the sex, BG indicates the Blood-Glucose, C is the creatinine value, BP refers to the Blood-Pressure, W is the weight, R is the race, D indicates if the user is undergoing dialysis therapy, T indicates if the user was transplanted.

SiD	A	S	BG			C			BP	W	R	D	T
1	74	M	131	131	134	1.23	1.07	1.2	135/90	77	Caucasian	no	no
2	66	M	89	89	85	2.5	2.04	2.16	145/80	73	Caucasian	no	no
3	84	M	83	81	80	1.4	1.2	1.3	130/40	50	Caucasian	no	no
4	64	M	96	90	100	9.76	11	10.5	120/70	82.3	Caucasian	yes	no
5	82	M	103	278	278	1.7	1.8	1.7	140/60	67	Caucasian	no	no
6	66	M	97	98	96	1.3	1.25	1.96	110/60	74.5	Caucasian	no	no
7	66	F	145	106	131	0.86	0.95	0.91	160/90	115	Caucasian	no	no
8	64	F	179	199	151	1.3	1.2	1.6	110/70	82	Caucasian	no	no
9	57	M	138	141	140	2.58	3	2.7	148/80	87	Caucasian	no	no
10	49	M	176	180	178	1.18	1.39	1.2	136/70	98	Caucasian	no	no
11	49	M	85	90	95	13.82	13.6	13.58	100/60	89	Caucasian	yes	no
12	35	F	111	88	92	9.6	8	7.67	140/80	54.5	Caucasian	yes	no
13	76	F	105	102	102	6.47	7.5	8.5	150/90	56	Caucasian	yes	no
14	52	M	103	102	103	11	10.5	10	110/70	82	Caucasian	yes	no
15	30	M	85	80	80	0.6	0.65	0.6	120/80	80	Caucasian	no	no
16	65	F	140	135	155	1.2	1.35	1.3	155/70	65	Caucasian	no	no
17	71	M	160	160	165	0.8	0.75	0.8	130/70	70	Caucasian	no	no
18	85	F	89	88	89	0.7	0.6	0.6	160/100	53	Caucasian	no	no
19	57	M	100	105	110	2.2	2.3	2.2	100/50	68	Caucasian	no	yes
20	19	M	85	85	90	0.6	0.65	0.7	115/85	75	Caucasian	no	yes
21	35	F	80	81	80	0.5	0.5	0.5	120/80	65	Caucasian	no	no
22	47	M	105	104	105	1	1	1	135/90	78	Caucasian	no	no
23	80	M	130	129	131	2	1.9	2	145/80	70	Caucasian	no	no

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Table 5 – continued from previous page

SiD	A	S	BG			C			BP	W	R	D	T
24	28	F	75	74	76	0.7	0.6	0.6	110/80	54	Caucasian	no	no
25	54	F	210	211	209	1	1.1	0.9	120/80	87	Caucasian	no	no
26	38	M	130	130	133	0.8	0.7	0.6	130/80	76	Caucasian	no	yes
27	69	F	120	119	121	0.7	0.6	0.8	140/70	65	Caucasian	no	no
28	43	M	90	78	75	1.8	1.8	1.9	120/80	70	Caucasian	no	no
29	64	F	100	99	103	0.7	0.6	0.5	127/60	65	Caucasian	no	no
30	53	M	145	143	146	2	2	2.2	150/80	70	Caucasian	no	no
31	70	M	101	100	104	0.95	0.9	1	135/80	70	Caucasian	no	no
32	56	M	97	97	97	1	1	1.1	120/80	78	Caucasian	no	yes
33	40	F	90	89	87	0.6	0.5	0.6	143/92	60	Caucasian	no	no
34	62	M	150	150	145	0.91	0.9	0.87	130/78	72	Caucasian	no	no
35	78	F	120	120	115	2	2	2.1	131/80	65	Caucasian	no	no
36	63	M	130	129	133	1	0.9	0.9	120/80	80	Caucasian	no	no
37	27	F	78	77	79	0.6	0.5	0.5	110/70	54	Caucasian	no	no
38	40	M	99	89	111	8	8	8	150/80	70	Caucasian	yes	no
39	59	M	140	140	141	5	5	5.3	140/90	69	Caucasian	yes	no
40	44	F	100	98	100	1.6	1.5	1.5	130/80	79	Caucasian	no	yes
41	60	M	95	96	96	7	7	7.3	141/96	80	Caucasian	yes	no

Table 6: Table reports both the diagnosis made by the doctors and the output of DIETOS profiling.

id	Nephrologist's diagnosis	Output DIETOS Profiling	TP	TN	FN	FP
1	arterial hypertension, chronic kidney disease and, diabetes mellitus	diabetes, GFR = 57.5 Stage3A (moderate CKD) follow Low protein salt calories diet, Hypertensive	✓			

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Table 6 – continued from previous page

id	Nephrologist's diagnosis	Output DIETOS Profiling	TP	TN	FN	FP
2	arterial hypertension and chronic kidney disease	No diabetes, GFR = 28.5Stage4 (severe CKD) follow Low protein salt calories diet, Hypertensive	✓			
3	arterial hypertension and chronic kidney disease	No diabetes, GFR = 5Stage5 (End stage CKD) DIETOS asks for transplant dialysis and provides additional info, NoHypertensive	✓			
4	chronic kidney disease	No diabetes, GFR = 28.5Stage4 (severe CKD) follow Low protein salt calories diet, Hypertensive	✓			
5	arterial hypertension, chronic kidney disease and, diabetes mellitus	diabetes, GFR = 36.7 Stage3B (moderate CKD) follow Low protein salt calories diet, Hypertensive	✓			
6	chronic kidney disease	Nodiabetes, GFR = 34.6 Stage3B (moderate CKD) follow Low protein salt calories diet, NoHypertensive	✓			
7	arterial hypertension, chronic kidney disease and, diabetes mellitus	diabetes, GFR = 70.6 Stage2 (milde CKD) follow Low protein salt calories diet, Hypertensive	✓			
8	chronic kidney disease and, diabetes mellitus	diabetes, GFR = 43.5 Stage3B (moderate CKD) follow Low protein salt calories diet, NoHypertensive	✓			
9	arterial hypertension, chronic kidney disease and, diabetes mellitus	diabetes, GFR = 22 Stage4 (severe CKD) follow Low protein salt calories diet, Hypertensive	✓			
10	arterial hypertension, chronic kidney disease and, diabetes mellitus	diabetes, GFR = 72 Stage2 (milde CKD) follow Low protein salt calories diet, Hypertensive	✓			
11	arterial hypertension and chronic kidney disease	Nodiabetes, GFR = 3.7 Stage5 (end CKD) DIETOS asks for transplant dialysis and provides additional info, NoHypertensive	✓			
12	arterial hypertension and chronic kidney disease	Low sugar tollerance, GFR = 4.8 Stage5 (end CKD) DIETOS asks for transplant dialysis and provides additional info, Hypertensive	✓			
13	arterial hypertension and chronic kidney disease	Low sugar tollerance, GFR = 5.7 Stage5 (end CKD) DIETOS asks for transplant dialysis and provides additional info, Hypertensive	✓			

Continued on next page

Table 6 – continued from previous page

id	Nephrologist's diagnosis	Output DIETOS Profiling	TP	TN	FN	FP
14	chronic kidney disease	Low sugar tollerance, GFR = 4.7 Stage5 (end CKD) DIETOS asks for transplant dialysis and provides additional info, Hypertensive	✓			
15	healthy	Nodiabetes, GFR = 134.9 Stage1 (normal CKD) DIETOS provides diet info, NoHypertensive		✓		
16	arterial hypertension, chronic kidney disease and, diabetes mellitus	diabetes, GFR = 63.1 Stage2 (milde CKD) follow Low protein salt calories diet, Hypertensive	✓			
17	arterial hypertension and, diabetes mellitus	diabetes, GFR = 89.9 Stage2 (milde CKD) follow Low protein salt calories diet, Hypertensive	✓			
18	arterial hypertension	diabetes, GFR = 79.3 Stage2 (milde CKD) follow Low protein salt calories diet, Hypertensive	✓			
19	chronic kidney disease	Low sugar Tollerance GFR = 32.1 Stage3B (moderate CKD) follow Low protein salt calories diet, NoHypertensive	✓			
20	healthy	Nodiabetes, GFR = 141.1 Stage1 (normal CKD) DIETOS provides diet info, NoHypertensive		✓		
21	healthy	Nodiabetes, GFR = 125.8 Stage1 (normal CKD) DIETOS provides diet info, NoHypertensive		✓		
22	healthy	Low sugar Tollerance GFR = 89.2 Stage2 mild CKD)DIETOS provides diet info, NoHypertensive			✓	
23	arterial hypertension, chronic kidney disease and, diabetes mellitus	diabetes, GFR = 30.6 Stage3B (moderate CKD) follow Low protein salt calories diet, Hypertensive	✓			
24	healthy	Nodiabetes, GFR = 118.3 Stage1 normal CKD) follow Low protein salt calories diet, NoHypertensive		✓		
25	chronic kidney disease and, diabetes mellitus	diabetes, GFR = 64 Stage2 (milde CKD) follow Low protein salt calories diet, NoHypertensive	✓			
26	diabetes mellitus	diabetes, GFR = 113.3 Stage1 normal CKD) DIETOS provides diet info, NoHypertensive	✓			

Continued on next page

Table 6 – continued from previous page

id	Nephrologist's diagnosis	Output DIETOS Profiling	TP	TN	FN	FP
27	arterial hypertension and, diabetes mellitus	Low sugar Tollerance GFR = 88.7 Stage2 mild CKD)DIETOS provides diet info, Hypertensive	✓			
28	chronic kidney disease	Nodiabetes, GFR = 45.1 Stage3B (moderate CKD) follow Low protein salt calories diet, Hypertensive	✓			
29	healthy	diabetes, GFR = 37.0 Stage3B (moderate CKD) follow Low protein salt calories diet, Hypertensive			✓	
30	arterial hypertension, chronic kidney disease and, diabetes mellitus	diabetes, GFR = 32.8 Stage3B (moderate CKD) follow Low protein salt calories diet, Hypertensive				
31	healthy	Low sugar Tollerance GFR = 80.8 Stage2 mild CKD)DIETOS provides diet info, No-Hypertensive				
32	healthy	Low sugar Tollerance GFR = 83.8 Stage2 mild CKD)DIETOS provides diet info, No-Hypertensive			✓	
33	arterial hypertension	Nodiabetes, GFR = 114 Stage1 (normal CKD) DIETOS provides diet info, Hypertensive	✓			
34	diabetes mellitus	diabetes GFR =90.0 Stage1 normal CKD)DIETOS provides diet info, NoHypertensive	✓			
35	chronic kidney disease	Low sugar Tollerance GFR = 23.4 Stage4 severe CKD)DIETOS provides diet info, NoHypertensive	✓			
36	diabetes mellitus	diabetes GFR = 79.7 Stage2 mild CKD) follow Low protein salt calories diet, No-Hypertensive	✓			
37	healthy	Nodiabetes, GFR = 137.8 Stage1 (normal CKD) DIETOS provides diet info, NoHypertensive		✓		
38	arterial hypertension and, chronic kidney disease	NoDiabetes, GFR = 7.6 Stage5 (end CKD) DIETOS asks for transplant dialysis and provides additional info, Hypertensive	✓			
39	diabete mellito, insufficienza renale cronica, ipertensione arteriosa	diabetes, GFR = 11.7 Stage5 (end CKD) DIETOS asks for transplant dialysis and provides additional info, Hypertensive	✓			

Continued on next page

Table 6 – continued from previous page

id	Nephrologist's diagnosis	Output DIETOS Profiling	TP	TN	FN	FP
40	chronic kidney disease	Low sugar Tollerance GFR = 38.9 Stage3b moderate CKD)DIETOS provides diet info, NoHypertensive	✓			
41	arterial hypertension and, chronic kidney disease	NoDiabetes, GFR = 7.7 Stage5 (end CKD) DIETOS asks for transplant dialysis and provides additional info, Hypertensive	✓			

Table 7: Recommender systems devoted to users affected by diet-related chronic diseases: comparison

Reference	Methodologies	Users Categories	**Clinical Experimentation**
PREfer [32]	Semantic-based with ontology	Diabetes, Hypertension	NO
Ge et al. [33]	Content-based	General use	NO
Chi et al. [31]	Semantic-based with ontology	CKD	YES
DIETOS	Knowledge-based	CKD, Diabetes, Hypertension	YES

6. Conclusion and Future Work

In this paper, we proposed an approach to profile health status of users and to recommend typical regional foods. DIETOS is a RS for the adaptive delivery of nutrition contents to improve the quality of life of both healthy people and individuals affected by chronic diseases. The proposed system can build a user's health profile, in particular, it can profile users affected by CKD, hypertension, and diabetes besides healthy users, and provides individualized nutritional recommendation according to the health profile. The profile is created through the use of dynamic real-time questionnaires prepared by medical doctors and completed by the users. This approach allows us to determine a medical-controlled user's health profile and to perform a fine-grained recommendation that is better adapted to each user's health status. Specifically, DIETOS suggests not only typical regional foods according to the user's health profile, but it shows the nutritional properties for each food stored in the database, and its benefits and side effects on pathologies and specific health conditions.

As future work, we intend to extend current DIETOS functionalities by advising users with diets and/or recipes compatible with their health status. Although DIETOS was originally designed to advice only Calabrian typical foods, we plan to introduce a set of functionalities that make easier for the specialists to add new typical foods or/and recipes as well as to follow the users' progress and motivate/communicate with them. Thus, it will be possible to increase the interaction among users and medical doctors, providing a richer user experience. Finally, by adding new questionaries able to profile new diseases as well as new specific conditions such as pregnancy, athlete and so on, it will be possible to advise more users with recipes and foods suitable for their health status.

The system prototype currently is under testing by the medical staff. The current version of the system available at www.easyanalysis.it/dietos is not indented to be used by general users, but only for review purpose.

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