# A Service-based System for Malnutrition Prevention and Self-Management

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**Abstract**. Malnutrition is considered one of the root causes for the occurrence of other diseases. It is particularly common in the aging population, where it requires more efficient handling and management to enable longer home independent living. However, to achieve a number of related challenges need to be overcome, especially those related to management of health and disease let alone other social and logistical barriers. This paper presents the design of a distributed system that enables homecare management in the context of self-feeding and malnutrition prevention through balanced nutritional intake. The design employs a service-based system that incorporates a number of services including monitoring of activities, nutritional reasoning for assessing feeding habits, diet recommendation for food planning, and marketplace invocation for automating food shopping to meet dietary requirements. The solution is deployed in small pilots in 12 elder adult houses that, in early results, demonstrate its holistic user-centred scalable approach for malnutrition self-management.

**Keywords**: Serviced-based design, malnutrition prevention, diet self-management, older adults, distributed systems.

## 1. Introduction

Older adults are particularly susceptible to malnutrition due to a number of factors, including decreases in appetite and sensitivity, lack of transportation, poor dental health, social isolation, physical difficulties, forgetfulness and so forth. Malnutrition can be defined as a state of nutrition in which a deficiency, excess or imbalance of energy, protein, and other nutrients causes measurable adverse effects on body form, function, and clinical outcome [1]. Various studies reveal escalating rates of malnutrition in the older population. For example, according to the British Association for Parenteral and Enteral Nutrition (BAPEN) [2], malnutrition affects over 3 million people only in the United Kingdom, and of these, about 1.3 million are over the age of 65. The most vulnerable group are the elderly who live by themselves, those admitted to hospitals, and those in nursing homes. Other studies found that up to that more than 60% of cases in nursing homes [3], and more than 15% of those living at home [2] are affected by malnutrition.

The consequences of malnutrition have significant impact on the older adults' health, including worsening of chronic conditions or delaying recovery from illnesses. These place huge demands on health and social services. These demands do not only include costs, but also logistical and capacity limitations. In fact, the cost associated with malnutrition in Europe is estimated to amount to a staggering 170 billion euro each year [4]. Therefore, if left unaddressed, it will eventually affect the whole society not only in the quality of services they receive, but also in their ability to meet these demands, in capacity, financially and other ways. Enabling the elder population to live longer at home is seen one of the most promising solutions. Not only to reduce costs, but also to address other psychological and social factors [4, 5]. The rapid identification of malnutrition and early prevention through the provision of nutritional assistance to the elderly is thus a critical factor to help not only to reduce costs, but also to enhance both the mental and physical conditions of older adults and their quality of life [6].

As part of the DIET4Elders project[1] [33], this paper presents the design of a service-based solution for homecare self-management focusing on malnutrition. It enables older adults self-manage their nutritional intake by preventing unhealthy self-feeding habits. The solution uses a distributed service-based design that incorporates several services:

(i) Monitoring services aimed at detecting food intake and activities.
(ii) Data collection and reasoning services to help the nutritionists to establish the degree in which the older adults follow their prescribed diet and to dynamically re-plan it.
(iii) Diet recommending services for planned long term diet plans that can be used and adjusted by dieticians.
(iv) Food generation services that can be used to generate longer-term diet interventions coupled with suitable meal and food plans.
(v) Marketplace services, which enable food providers to register their services and offerings.
(vi) Food shopping services that enable the dynamic selection, based on the prescribed diet, of suitable food service providers, potentially enabling automated shopping.
(vii) User feedback and reporting services, to assist older adults and their informal carers during daily self-feeding activities aimed at creating a continuous feedback and interaction loop not only to detect and prevent the instauration of malnutrition, but also other health issues.

[1] Dynamic nutrItion bEhaviour awareness sysTem FOR the Elders (www.diet4elders.eu)

The rest of the paper describes the system design and services that DIET4Elders intends to develop in close collaboration with its target older adults. Section 2 presents the state of the art in the area of nutrition self-management, Section 3 presents the malnutrition prevention process as implemented in the DIET4Elders project, Section 4 describes the overall design of the system services while section 5 presents the technological choices for their implementation.

## 2. Related Work

Most of the state of the art of diet (self) management solutions and approaches aim to provide food recommendations based on the nutrient information for popular products, and to define customized weight loss and healthy lifestyle plans [13], [14]. Although these approaches are intended for a wide spectrum of people groups regardless of age, they do not address the specific problems and causes of older adults regarding malnutrition prevention and self-feeding behaviours, failing to consider related challenges and issues including contextual and circumstantial ones, thus the proposed approach by this paper. .

Al-Dhuhli et al. [15] propose a food recommender system based on prior evaluation of nutrition intake and physical activity levels during the day period. The system is based on nutrition related knowledge provided in the form of "if then" rules. Although the system is evaluated using experts and different user groups, it does not involve complex nutrition behaviour reasoning processes, limited to generating simple outputs such as BMI (Body Mass Index) values, nutrient values or weight information. Another system for daily menu recommendation based on reference values of daily calories of a person is developed in [16]. The authors propose a fuzzy based inference engine to assess the daily food intake. The approach is limited to some nutrients making it suitable only for losing weight based on low calories intervention plans. A more sophisticated reasoning approach was proposed in [17]. In this approach, the authors propose a nutrition expert system using a rule-based inference engine and multi-objective linear programming models for dietary recommendations. The system generates eating-plans that conform to the nutritionist specifications, considering the preferences of end-users and food items cost. A similar recommender system for menu planning in a restaurant is proposed in [18]. The system uses a food ontology, which contains specifications of ingredients, nutrition facts and recommended values for daily intake. The system implements an inference engine for the defined ontology, and web interfaces customized for the needs of food customers and dieticians. The system is not able to adapt and personalize the provided menus and recipes for specific nutritional profiles of food customers. The authors of [19] proposed a different approach for recommending meals recipes with an aim to promote the intake of healthful food choices. The system offers meal-planning functionality and implements a simple intelligent decision algorithm to provide recommendations based on the nutritional values of each ingredients part of a recipe. An alternative method is described in [20], in which the Intrapersonal Retrospective Recommendation method is introduced for generating recommendations on dietary and lifestyle changes. Recommendations are based on predicting the individuals' unhealthy behaviours based on prior behavioural patterns in pervious periods of success at lifestyle change or maintenance.

For mobile computing users a number of methods have been reported. In [21] a personalized daily menu recommendations system for mobile devices is proposed. The proposed system is based on predefined rules for foods and dishes and employs a genetic algorithm to calculate the fitness of candidate solutions using personalized target values of various nutrients. Another mobile application for dietary management that considers a person's food allergies is described in [12]. It is based on end-user food diaries filled using a barcode scanner, electronic patient records for identifying the specific allergies and food products databases. However, the application is not suitable for un-labelled food or for food cooked at home. Another healthful nutritional improving method was described in [22]. They used mobile devices to monitor 27, aged over 50s users' vegetable and whole-grain intake levels twice per day and provided daily-individualized age-appropriate feedback, goal-setting, and support, over 8-weeks period. The results have shown that the participants reported significantly greater increases in vegetable servings (1.5-2.5 servings/day), as well as a trend toward greater intake of dietary fibre from grains (3.7-4.5 servings/day), but it needed very close involvement of nutritionist to provide advice. A more scalable approach was suggested using a service-based system for nutrition diagnosis by [23]. It employed the use of the BMI evaluation of end-users and nutrition intervention rules coded in Jess, a Rule Engine for the Java Platform. The system sends notifications to the end-users regarding the meal time and suggests healthy food places nearby, but had little control on the outcomes. An alternative web-based application for nutrition diagnosis that utilizes expert system techniques and artificial intelligence is proposed in [24]. The authors have implemented a Nutritional Care Process and Model and integrated the nutrition diagnosis knowledge from dietetics professionals to develop a rule-based system and associated knowledge. Similarly the system failed to control diet imbalance and nor provide continual food recommendations for long-term unbalanced dietary habits.

The above approaches partially address elders nutrition related problems and fails to provide a holistic approach to malnutrition and diet management that covers the entire lifecycle of a nutrition care process (from monitoring to intervention and reassessment). The solution proposed in this paper progress the existing state of the art through defining a continual, dynamic and more scalable approach using service-based methods that employs services covering the entire, highly interactive complex, nutrition care process tailored to the elders' needs. The nutrition care process includes a continually invoked set of processes, with a number of stakeholders, contributing to each stage, that are required to interact to achieve an optimal outcome. Thus, a service-based approach is proposed to address the complexity of the nutrition care process by splitting the process into roles and functions and thus services to handle the different yet complimentary interacting processes into a more dynamic, efficient and responsive outcome. This allows services to represent different part of the care process from monitoring, through detection to prevention, accordingly is well placed for the elderly adults. Monitoring and detecting the elders' food intake in home settings is done with minimal intrusion, utilising user-friendly graphical user interfaces fit to the elderlies' capabilities and ease of use. The proposed system allows defining personalised suitable diet plans that meet the needs of not only healthy individuals but also of those with common chronic diseases, such as diabetes or those with cardiovascular problems. The elders' food intake is continually assessed and evaluated against the defined personalized diet. A suitable food is recommended, from food service providers' offerings available in a provided food marketplace, to meet nutritional and dietary needs to maintain a health diet intake. The system also supports (food) service dynamic selection, based on the prescribed diet, from suitable food service providers, thus potentially enabling automated shopping. To achieve, the solution developed an approach that utilises a fitness function to select optimal bio-inspired search techniques for best processing overhead based on differing search characteristics.

## 3 Malnutrition Prevention Process

Malnutrition prevention process includes a set of continuous looping steps that starts with monitoring, to collecting food intake information, with each step building on the input of the previous step, as illustrated in Figure 1. In practice, the *screening* (in the community or by non-nutrition specialists) triggers a referral to a nutritionist or dietitian for a more in-depth assessment and as a result a 'nutrition care plan' is then developed. Hence screening is almost a 'pre-step' of nutrition care process, which does not need to be executed each time the nutrition care process runs. The first stage (*monitoring*) feeds new data into the second stage (*assessment*), i.e. it triggers a re-assessment to determine if the previous dietary plan is still relevant or if changes need to be made to reflect the progression of previously identified, or possibly the development of new, nutritional problems. Factors influencing the implementation of the intervention (for example, social and financial changes) are also identified during the monitoring stage. Final assessment is eventually confirmed by a dietician but aided by the system to enable reaching a more dynamic early assessment, especially to enable detecting malnutrition patterns over long periods through the continual analysis of and to help identify problems in the current food intake regime. The third stage (*individualized dietary plan prescription)* enables proactive the definition of nutrition intervention schemes that allow the prevention of a problem before its actual instauration. Individualized dietary plans are defined, but revised regularly, consisting of personalized nutritional goals that an elderly must follow. The fourth stage (*intervention*) defines the type of actions that may be taken in case a nutrition problem or unhealthy behavior that may lead to malnutrition is identified for an older adult. Three types of actions are available: food ordering, feeding assistance (especially important in elders that may have difficulties in chowing and swallowing) and nutrition education. For food ordering, different foods are suggested to comply with the nutritionist's prescription and nutrition-related monitored information. If it is inferred that using food ordering can no longer balance the daily intake (i.e. there is severe violation of the dietary plan), alarms are generated not only for for the older adult, but also their associated carer and nutritionist. The nutrition education actions aim at educating the older adult to eat healthy by building or reinforcing basic nutrition related knowledge in strict relation with the assessed nutrition related problems.

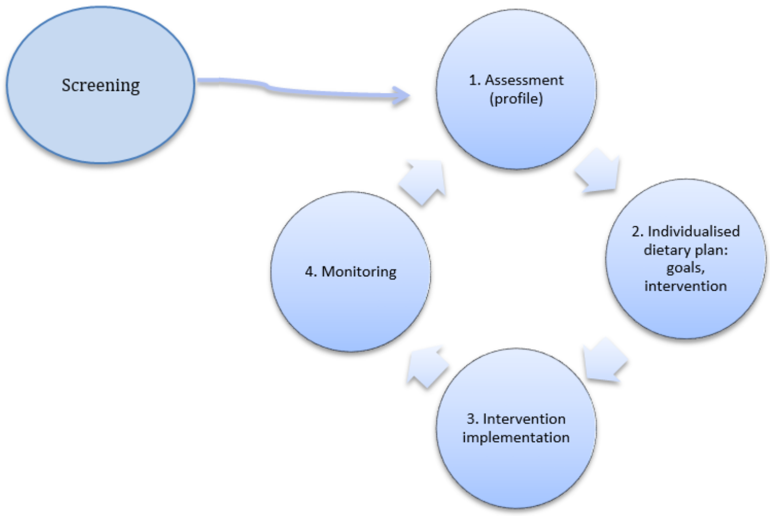


**Fig. 1. Nutrition care process for malnutrition prevention**

There are a number of standardised models of the *nutrition care planning process*, most notably the Academy of Nutrition and Dietetics' Nutrition Care Process and Model [11]. The British Dietetic Association has a similar version, known as the Model and Process for Nutrition and Dietetic Care [9], and dietetic associations from Canada and Australia use similar processes and models. The international dietetics community is working to develop a standardised language for documenting the nutrition care process [12]. Within Europe, take up by the profession has been slower, but there is a vision for the adoption of a standardised care process and language to be used by all dietitians, and in the training of dietitians, by 2020 [10]. Standardising such models would enable the implementation of a more automated process of managing it. Of particular value is reaching and determining the exact nutrition data points of interest to collect and analysis results of significance to prompt and invoke the appropriate next intervention step. However, this can be a complex process given the variations in food intake that are often influenced by several factors including cultural as well as personal habits, and governed by other specific factors including medical conditions, level of physical activities and availability of recommended diet. Therefore, creating computation models augmented with semantic variations and run through computational services would enable creating a more efficient, dynamic, scalable and timely process to manage malnutrition. The overall system design to achieve such process is described in the following section.

## 4. Overall Service-based System design

The overall system design is shown in **Error! Reference source not found.**. The design uses services to enable collecting nutritional related data and providing the related recommendations directly to the older adults in their home environment as well as to their dietician and informal carers. The design include a number of services to achieve a complete cycle of monitoring diet intake and user related activities, analysis of collected data, through reasoning over collected data and producing diet recommendations to providing food ordering services, these are described in more details below.

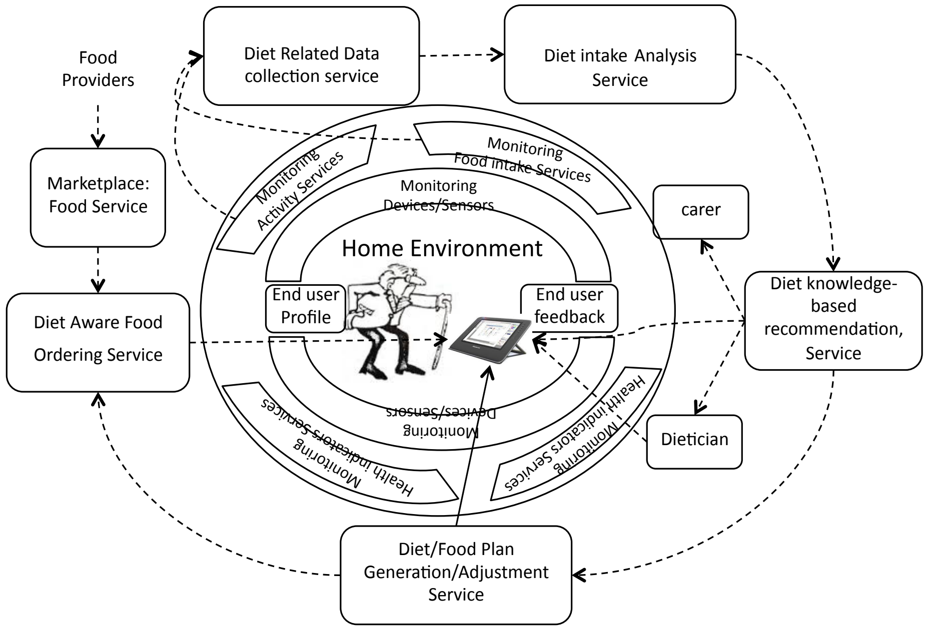


**Fig. 2. Service-based Self-management for malnutrition prevention**

***Monitoring Services and Diet related Data Collection***

Data collection includes a number of monitoring services. It relies on self-reporting and home environment monitoring infrastructures, where wireless sensors are used to detect and collect related diet data including food intake, activities, health data and so forth. For similar types of sensors (e.g. activity sensors), data monitoring services are created that collect the relevant data. A local communication infrastructure pushes the data to respective data monitoring services, which pushes data to the data collection service. This is enabled by the use of advanced sensors technologies to track and detect older adult's daily activities and the context in which these activities took place. The project is looking at using and/or where not available developing advanced wireless non-intrusive sensors that monitors the daily diet intake and physical activities aspects of older adults, including smart containers, smart fridges, accelerometers, health monitoring devices, positions sensors, RFIDs, smart tablets or phones etc.

The diet related data collection service aggregates data from all monitoring services, which are further semantically categorised to enable both context and semantic analysis linked to temporal and longitudinal diet behaviour. Valid and effective diet advice is one key objective of the design to base itself on evidence from collected data. This, thus, is pinned by the need to build a dynamic mechanism not only closely linked to accurate (data collection or) monitoring technologies but also based on evidence-based diet knowledge. For such, the project has developed a computational representation of diet/nutrition knowledge drawn from existing well-established diet evidence [10]. It is drawing knowledge with standardised units and measurements to be able to computationally reason over such knowledge correlated to the specific knowledge collected about individual users, taking into account not only their level of health and chronic diseases that they suffer from, but also the context and culture variations. These three aspects provide the semantic representation or model for reasoning, including user-context (e.g. weight, age, preferences etc; chronic diseases etc); user-activities (e.g. physical activities etc.); and diet intake and nutrition/diet knowledge.

***Food Intake Analysis, Assessment and Diet Recommendation Services***

The intake analysis and assessment need to be able to reason over collected data to drive and identify self-feeding behavioural patterns that lead to malnutrition and create counter mechanisms to address them. This includes the development and employment of reasoning techniques including graph theory and prediction techniques to discover patterns from chain of activities abstracted to the diet and context of use. With direct input from nutritionists, it uses learning algorithms with continual feedback and human intervention to achieve more precise and accurate identification of unhealthy behaviour patterns. Next section describes this in more details.

Analysis and assessment services feed their results into diet recommendation services. The system employs a number of services that interconnect with the above technologies to circumvent unhealthy feeding behaviours and interconnect with the older adults directly so they are aware of where they could improve on their feeding habits. These also provide intelligible and useful feedback to both carers and dieticians to monitor changing behaviours in feeding patterns. The key is to produce current and quantifiable information of value to the older adults as well as their dieticians (i.e. personalized diets, nutrition goals, etc.). Given the amount of data collected over time, this becomes a complex data-mining issue, potentially requiring large computational resources required to produce meaningful information in a relatively short time for potentially large number of users. Thus the system design employs a distributed infrastructure to enable such analysis. The outcome of these services, using a scalable computational representation of analysis results, is further used by the system and subsequent services, to draw relevant diet recommendation decisions. Given the sensitivity and impact of these recommendations on the older adult health, continual expert reviews of the validity of drawn results and discovered patterns are integrated within the services workflow. This employs short-term reasoning and long-term reasoning. The former is to identify short-term nutritional issues that would require more immediate response, e.g. diabetes and elevated intake of sugar. The latter is to discover long term patterns in food intake that will eventually lead to malnutrition. The reasoning methods are described in more details in section 5.

***Food and Meal Plan Generation Services***

These services receive unhealthy behaviours, nutritional deficiencies information and personalized nutrition goals into a computational form from the assessment and recommendation services. This information is then used by diet plan generation services, to draw actionable food intake meals and food plans that can overcome identified diet and nutritional deficiencies. These draw a longer-term individual plan for each, based on the older adult preferences, their health profile and their chronic illnesses. Dieticians are able to adjust these plans based on further discussion and feedback from the user. User feedback is critical to incorporate in the process for these meal plans uptake so they eventually result into effective outcomes [5]. These take a number of various factors into consideration, including health, contextual and cultural variations. The prescribed diet is then used for dynamically selecting the suitable food service providers from the defined Food Marketplace services described below, potentially enabling automated shopping

***Marketplace Services***

There are a large number of potential food providers with different capabilities and offerings that already provide meal services to older adults, in both nursing homes or at home. However, these mostly employ a manual process to describe offerings thus match them correctly to older adults' diet requirements ??? and not all provide all types of meals to meet all their customers' exact diet requirements. The system provides a service-based mechanism with well-defined diet specific marketplace that allows food providers to register their services and food offerings, as illustrated in Figure 3. It uses reliability-augmented service descriptions and mechanisms with clear quality indicators that not only enable users to have informed decisions about the food ordering but also enables the system to make informed judgement of suitable combination of food ordering with suitable levels of nutrition that meet the specific needs of the user. They include mechanisms to capture and validate key quality indicators of food services, not only at the service level but also at nutritional and contextual levels. Services registered within the marketplace conform to a rich description specification, capturing necessary nutritional aspects and other food-related characteristics (such as ingredients, cuisine, etc.). This enables diet-aware and personal profile-aware selection of food services for older adults. In addition, through key performance monitoring and prediction mechanisms, the reliability of the registered services is assessed with respect to a number of relevant food service quality-indicators, thus provides a more dependable system for the purpose.

However, service selection and composition is a complex and computationally intensive problem. Specialised food services that offer such requirements are increasingly becoming available across many countries, given the recent surge in aging populations. For such marketplace, the larger the number of food services to offering the different varieties of foods and meals, varied across cultures and preferences, the more demanding it becomes to generate a more reliable set of food services that meet highly reliable and dependable needs of a relatively vulnerable elderly community. Therefore, a QoS framework has been developed that utilities these needs. The work is based on a multi-granularity service model that comprises of four components of knowledge of food services maintained within the marketplace [8]. These components include, abstract service hierarchy, quality meta-model, service model and reliability model. The abstract service hierarchy addresses the different level of granularity of food services and their offerings, from being at the ingredient to the meals levels, and stores such knowledge as a hierarchy to enable service composition at the appropriate level. The quality meta-model enables accommodating the various elderlies' food QoS preferences, from cultural, contextual, personal and medical aspects. Examples of these preferences include customised diet, specific nutrition, geographical coverage, cost, delivery and so forth. The service-model describes service description representation of each service within the market, to assess its suitability and enables its selection based on the quality meta-model parameters. Reliability model constructs a history-based usage as well as quality indicators assessment mechanism to reach and determine reliability measures of services. The development of this work has been described in more details elsewhere [8].

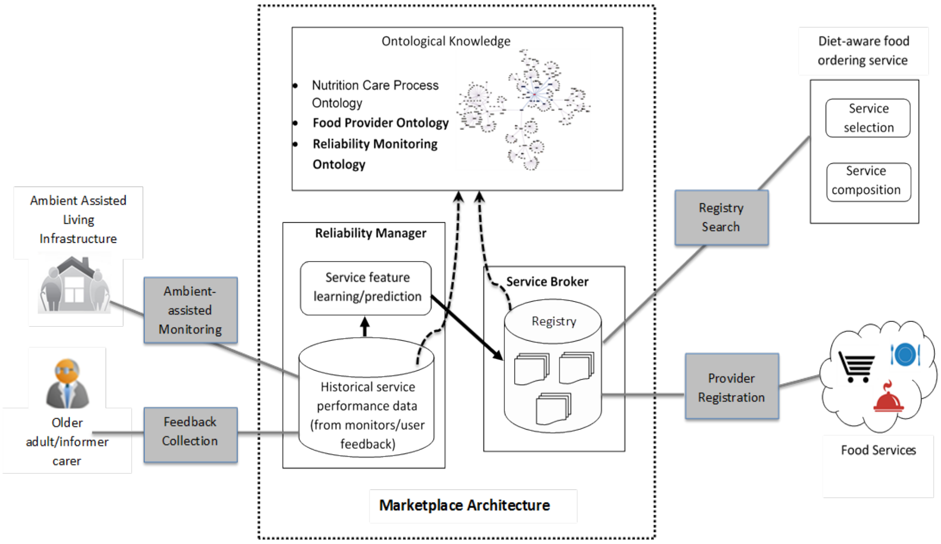


**Fig. 3. Marketplace for food services**

### *Diet-aware Food Ordering*

For meeting complex diet requirements and/or user preferences, several food providers offerings are required to be aggregated and combined. The selection of the combination of food services, to satisfy potentially complex criteria of the older adult recommended diet or preferences, is thus a non-trivial task. There are a large number of food delivery services available in the market place offering various types of food, which makes finding optimal combination a NP-hard problem, which cannot be solved in reasonable time using conventional search techniques. The system models the problem as a combinatorial optimization problem and solves it using hybrid bio-inspired techniques [9, 32]. The use of these techniques is necessary to combine the strength elements of different meta-heuristics into converging to an optimal solution in the shortest possible time or that requires lowest processing overhead. The system selects, based on the in-hand different meta-heuristics elements, one of a set of pre-defined bio-inspired search algorithms, e.g. Ant Colony [Ref], that provide best potential convergence time or processing overhead. This approach requires further experimentation as the number of food services in the market place increases and thus different combinatorial factors, including food offerings, contextual, cultural, QoS, etc, data grows in size, where different competing algorithms may be suitable for use. This is described further in section 5.

## 5. Technology Challenges and Decisions

Figure 4 presents an overview of technology chosen for implementation and their mapping onto the designed services.

The *Monitoring Services and Diet related Data Collection* goal is to, non-intrusively, gather data relevant to the older adult's nutrition care process and malnutrition prevention. Given the particular needs of the target end-users of the DIET4Elders and their accessibility needs, as well as to facilitate *collection of the needed information and data* to be able to prevent malnutrition through guiding and encouraging healthy self-feeding behavior, such information/data must be captured with minimum intrusion and effort. Thus, the project employs two data acquisition strategies: implicit and explicit (see figure 5).

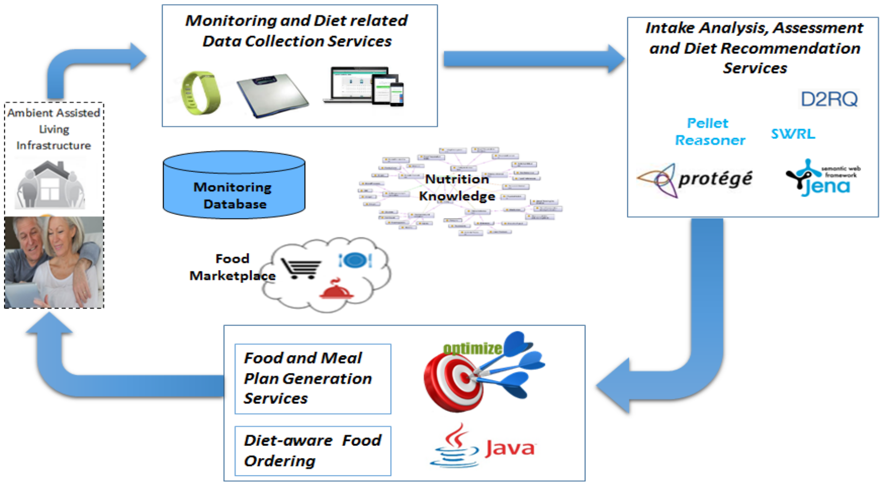


**Fig 4. Malnutrition prevention services technologies**

The *first* involves acquiring data through the use of *smart sensors* implanted within a distributed wireless networks in the elderly's homes integrated within their living environment to monitor their nutritional intake and health. Also, some information is collected from ordered foods through the marketplace as well as directly through the food providers, including nutritional values, quality assurance aspects, delivery details, and so forth. The *second* collects data from the older adults themselves by means of *self-reporting questionnaires* and includes active involvement of their carers and dieticians to enrich the outcomes of the assessment process to reach more informed decisions driven by evidence. .


**Fig 5. Monitoring Services and Diet related Data Collection**

Defining and representing *Nutrition Knowledge* is fundamental for allowing analysis services to reason about it, and to provide personalized diet intervention and feedback. The nutrition knowledge base is represented into a structured format, on which rule based reasoning is employed to assess the nutrition related behavior of a person. Ontology representation is used for knowledge representation, which was the best candidate for representing standard models, taxonomies, vocabularies and domain terminology within the nutritional domain, complimented by a choice of suitable semantic reasoning engines. More details about our Nutrition Knowledge Ontology can be found elsewhere [25].

For the *Intake Analysis, Assessment and Diet Recommendation Services* a semantic inference engine was designed. It consists of the following tools (see Figure 6): (i) Protégé [26] for implementing the concepts and properties of the Nutrition Knowledge Ontology, (ii) Jena framework [27] which provides the API to process RDF data, (iii) D2RQ [28] for mapping individuals from the ontology with entries from an SQL database and (iv) Pellet reasoner [29] for evaluating the defined nutrition rules on the ontology. The nutritional values for each specific type of food are taken from the McCance and Widdowson's food composition tables [30], which provide the description of around 3400 food items. Based on these nutritional values, the ontology individuals that represent specific food items are created and classified in the food ontology.

Due to the large number of ontology concepts describing food items that need to be instantiated and classified in the defined taxonomy, this process cannot be done manually. On the other hand, there is an evident need for ensuring a semantic validation and automated reasoning on the data provided which cannot be achieved using the relational database representation of data. To address this requirement, the adopted solution was to store data regarding food items and their nutritional information in a relational database and to map the ontology concepts onto the database tables to obtain concept instances. Different alternatives to connect and map the ontology to a relational database are reported in the literature [31]. The solution was adopted taking into account the following criteria: how the individuals will be persisted in a relational database; whether the ontology will be written in a specialized tool; whether a reasoner will be used to infer new knowledge from the already existing data; and whether data will be queried by using a specialized language. We chose to use D2RQ as it allows for managing classes, object properties and data properties in the form of database tables with a clear separation between the ontology data (individuals), ontology structure. D2RQ can be easily integrated with Jena which is a powerful, fit for purpose, tool when associated with description logic reasoners for reasoning on ontologies.

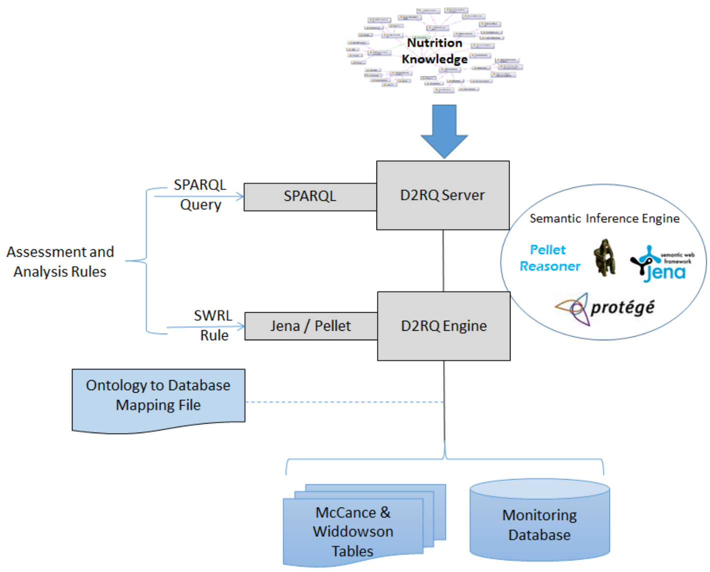


**Fig 6. Semantic inference engine**

In case of the *Food Menu Plans Generation and Diet-aware Food Ordering* the bio-inspired algorithms are implemented in Java using the following steps (see figure 7):

(i) optimization problem needs to be formally represented and the search space defined,
(ii) concepts of the optimization problem must be mapped to the meta-heuristic concepts and appropriate fitness functions need to be defined,
(iii) meta-heuristic's algorithm needs to be adapted/enhanced according to the optimization problem being solved.

For the *first step*, the search space is defined as the set of food services available in the marketplace that are semantically annotated with information regarding various aspects of nutrition (such as organic composition, energetic values, calories etc.) and food quality and reliability. This information is provided during the food provider registration stage. The personalized diets and nutrition goals drive the food selection and combination process, while the users' preferences and needs are used to refine the results.

The *second step* maps the concepts of the optimization problem to the concepts of the chosen meta-heuristic and provides an appropriate formal representation of these concepts to enable a low processing overhead. On the search space, the system define a set of fitness functions (e.g. a fitness function evaluating the number of calories which needs to be minimized based on the food descriptions provided by the food delivery services) that evaluate the quality and reliability of a food service combination according to the criteria (e.g. number of calories) established in the older adult recommended diet.

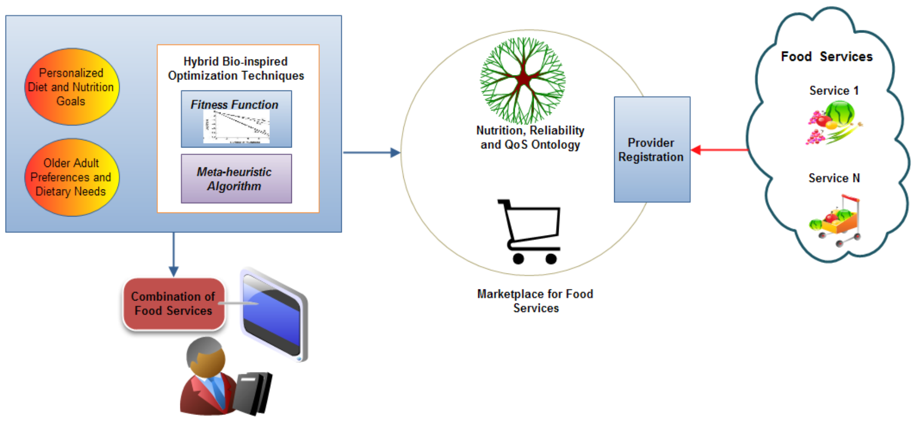


**Fig 7. Diet aware food ordering**

The *third step* implies the algorithm specialization according to the problem being solved and additionally including some supplementary processing steps to provide a balance between exploration and exploitation. For example, if the Ant Colony Optimization meta-heuristic is considered, it uses a number of intelligent agents (i.e. implementing the ants behaviour) that cooperate with each other by indirectly exchanging information (i.e. the ant's pheromone in nature) to identify the optimal or a near-optimal food delivery service combination (i.e. the ant's food source in nature) encoded in the search space (i.e. the environment in which real ants live). Further detailed descriptions of our bio-inspired meta-heuristic implementations are provided in [32].

The *services front-end development* was conducted using a user centric approach and continuous feedback for elders to assess its usability. The key output of such assessment is both to ensure the usefulness of the system as well as the continued development of a more adaptive integrated distributed environment and system that meets the needs of its users, including the carers, as well as scales to demands on the number of service providers. One key challenge was to reach a state of usability of the overall system to overcome acceptability issues of such technologies by the older adults, although a final version of promising example have been demonstrated by another project [5]. Another challenge was to develop a computational quality assurance process to enable proper vetting of service providers as well as their adherence to respective food and service standards. A version of the system's user interfaces has been implemented and evaluated by 12 users but requires further ongoing evaluation of use by a larger number of users.

## 6. Evaluation Early Results, Conclusions and Future work

The paper presents a service-based distributed system design and architecture for malnutrition prevention and self-management. It describes briefly the design and the employed services that will be used by the project to enable self-management of a balanced nutritional intake based on monitoring daily activities, and self-feeding habits. The project builds its solution using a service-based design and employs a number of services to provide nutritional advice, interact with dieticians and carers, and enable food ordering through a reliability-augmented and well-specified marketplace. Although the solution is based on malnutrition management, but it presents a generic solution which can be used to enable effective management of demanding requirements of large data collection and analysis for homecare environments within a distributed setting. Such system design need to meet potentially very large-scale requirements, especially as it is required to serve large number of older adults, geographically distributed at their homes, with varied and complex health needs.

The second version of the design is already being developed part of the project with anticipated incremental planned evaluation and deployment of its components in selected older adults homes. Given the amount of potential data generated by monitoring services, other design considerations will look at the use of big data techniques for data management and analysis. The project's first version has been deployed in 12 end-user elderly adult houses in Spain (Galicia). A number of aspects of the systems are being continually evaluated, including, diet related data collection, reasoning for identification of malnutrition and user interfaces. Also, data collection for other aspects related to scalability, diet-driven food service selection and composition from the marketplace based on diet QoS factors, automated shopping, and long-term malnutrition diagnosis and identification and management, is in place but require larger amount of data for valid results. A limited number of food-ordering services, including food real services from a project partner, COESCO, located in the same region, have been added into the market place selected to match the characteristics of the participating end-users. Early results indicate reasonable and promising outcomes on identifying short-term identification of malnutrition issues and the reasoning approach. It addition, they indicate the adopted diet QoS-based food service search and selection to enable automated shopping is sufficient, however it needs a much larger number of food-services for a more comprehensive evaluation. The results also indicate that while carers' and dieticians' interfaces received reasonable acceptance, more work is needed on re-designing a more intuitive user interface that requires accessibility-supported user interactions, carefully optimized for minimal data collection suitable for older adults. However, further larger scale evaluations are being planned to allow handling larger number of end-users, food ordering services and larger nutritional reasoning cases, to evaluate the scalability of the approaches.

The paper reports a number of challenges in realizing the proposed design, technological and otherwise, requiring a sophisticated integration of various technological as well as computational environments within a home-based care settings with unique end-users. Challenges also included developing methods to ensure the reliability of food provisioning, the support of multi-cultural multi-granularity framework of service composition and selection, the acceptability of sensor-driven monitoring of older adults' nutritional behavior and on-time responses to preventing or treating malnutrition and the ability to adapt to different personal and cultural preferences within a dynamic framework governed by medical needs of vulnerable end-users.

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