A Smart Computing Framework Centered on User and Societal Empowerment to Achieve the Sustainable Development Goals

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Abstract. Today's world is facing several grand challenges and pressing problems. As a way of calling for action to address these challenges, the United Nations has developed 17 Sustainable Development Goals (SDGs) to transform our world. Smart Computing aims to combine advances in Information and Communication Technologies including Internet of Things, cloud computing, mobile computing and social computing to create smart systems to make human life better. Smart Computing is providing a new approach to address many of the complex and challenging problems and a valuable tool to support progress towards many SDGs. The lack of a suitable framework to handle the complex multi-disciplinary nature of these applications is hindering sustainable development. Based on a series of solutions we have developed for agriculture domain to address the first three SDGs (i.e., No Poverty, Zero Hunger, and Good Health and Wellbeing) we proposed a smart computing framework centered on user and societal empowerment. This framework consists of six dimensions: Economics, Domain Knowledge, Interaction Design, User Interface Design, User Empowerment and Societal Empowerment. As a way of validation, we have adopted this framework to design a mobile-based information system to address "Hidden Hunger" in African countries and carried out a preliminary evaluation. Having the framework to guide our thinking and designing of the solution helped us to frame a holistic solution centered on user and societal empowerment. The proposed framework can be adopted to develop effective and innovative solutions to address many SDGs targets.

Keywords: Smart Computing, User and Societal Empowerment, Nutrition, Food Security, Sustainable Development Goals.

1 Introduction

Today's world is facing several grand challenges and pressing problems. In order to address these challenges and improve the lives of people, countries around the world now have agreed that sustainable development is the best pathway to promote economic opportunity, better social wellbeing, and protection of environment. This motivated the

United Nations to formulate 17 global goals - the Sustainable Development Goals (SDGs), which are aimed to transform the world we live in by 2030.

Smart Computing is an effective method to integrate the capabilities of computer hardware, software, social media and communication networks together with digital sensors, smart devices, Internet of Things (IoT), big data analytics, computational intelligence and intelligent systems to realize various innovative applications [1]. Smart Computing is a multi-disciplinary domain and can be broadly classified into two major areas: how to design and build smart computing systems and how to use computing technology to design smart solutions to make human life better. Smart Computing can be used to provide new solutions to many challenges faced by humanity and address many SDGs targets.

In order to achieve the SDGs, development programs need to reach billions of people across different continents irrespective of any country's development status. This is a very complex challenge. The lack of a suitable framework to handle the complex multi-disciplinary nature of these applications hinders finding effective and long-term solutions to these issues. What we see today is a very large number of "apps" providing point solutions to various human needs rather than offering an integrated system to solve a complex human problem.

This paper presents an approach to utilize Smart Computing to develop a multi-disciplinary solution to a complex problem using Systems Engineering approach to make human life better. The approach is based on a series of solutions we have developed for the agriculture domain to address the first three SDGs (i.e., No Poverty, Zero Hunger, and Good Health and Wellbeing). It consists of a smart computing framework centered on user and societal empowerment. This framework combines six dimensions, namely Economics, Domain Knowledge, Interaction Design, User Interface Design, User Empowerment, and Societal Empowerment, to formulate a solution.

The proposed framework has been used in the design of a mobile-based information system to address "Hidden Hunger" in African countries. Hidden Hunger is a form of malnutrition arising from diets that, although generally adequate in energy, are inadequate in terms of micronutrients, leading to micronutrient deficiencies[2]. Having the framework to guide our thinking and the design helped us to develop a holistic solution centered on user and societal empowerment. An initial evaluation with domain experts and end users demonstrated the potential of the framework and the resulting mobile artefact to address such pressing societal issues.

In summary, the contributions of this paper are the following:

- It proposes a framework that enables us to combine six dimensions centered on user and societal empowerment to develop solutions to large-scale and complex humanitarian challenges.
- It presents a real case study in the use of the framework to tackle hidden hunger in African countries, from the inception of the system to end-user evaluation.

This paper is organized as follows: Section 2 provides the background that lead to formulation of the framework. Related work is discussed in Section 3. The proposed framework is presented in Section 4. Adoption of the framework for a case study and its evaluation are explained in Sections 5 and 6, respectively. The conclusions and future research direction are presented in Section 7.

2 Background

The world population now exceeds 7.06 billion people. Developing countries accounted for 97 percent of this growth. At present, about 60 percent of these people are classed as rural; of whom around 85 percent are agricultural. It is estimated that across the developing world, a total of 1.2 billion people live in poverty [3]. The evidence is clear that broad-based agricultural development provides an effective means of both reducing poverty and accelerating economic growth.

In order to illustrate the existing challenges with a concrete example, we explore a case study from Sri Lanka [4]. In Sri Lanka, agriculture is one of the important sectors and approximately 33% of the total labor force is engaged in agriculture [5]. Coordinating agriculture production among a large number of small land holdings is a major problem. The main issue in an uncoordinated agriculture domain is over production of some crops while some others are in short supply, leading to widely fluctuating market prices. An in-depth analysis of the problem revealed that the root cause of the problem was that farmers and many other stakeholders in the domain did not have access to correct, up-to-date, complete information in a suitable modality and on time for decision-making. Farmers need published information (quasi static) about crops, pests, diseases, land preparation, growing and harvesting methods, and real-time situational information (dynamic) such as current crop production and market prices. This situational information is also needed by agriculture department, agro-chemical companies, buyers and various government agencies to ensure food security through effective supply chain planning whilst minimizing waste.

Inspired by the rapid growth of mobile phone usage in Sri Lanka, including among the farming communities [4], a mobile-based solution was sought to overcome this information gap. In 2011, an international collaborative research team with members from Sri Lanka, Australia, Italy, and United States embarked on a project to address this problem by developing a mobile-based artefact to enhance the flow of information among stakeholders in the agriculture domain[6-8]. This was a complex problem with many research challenges. Due to the complexity of factors that affect supply and demand in the agriculture domain, it was very difficult to identify the deeper requirements that an artefact should address to achieve a good coordination between the two. Thus the team used an iterative process building many functional prototypes and validating the relevance of these artefacts to address certain symptoms of the problem to finally discover the requirements the overall artefact should fulfil [9, 10].

The different artefacts were integrated to create a new mobile-based solution that was later conceptualized as a Digital Knowledge Ecosystem [11]. This system can now predict current production situation in near real time enabling government agencies to dynamically adjust the incentives offered to farmers for growing different types of crops to achieve sustainable agriculture production through crop diversification [4]. In 2016, the Sri Lankan Government announced this as a National Project in that year's

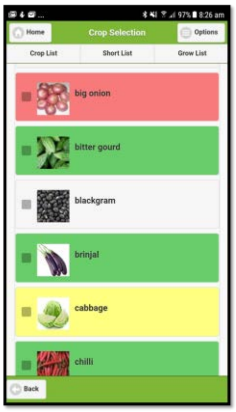
Budget Speech. The system that was originally developed for farmers in Sri Lanka is now being trialed by 5000 farmers in India.

There are several insights about this project that can be considered. Firstly, this case study illustrates the implications of a lack of multi-level coordination; matching supply and demand, coordination of input supplies and selling activities. The root cause for all these were identified as users not getting right information at the right time. The case study also presented the evolution of a Smart Computing solution to address these failures. To achieve a better match between supply and demand, farmers wanted to know (a) what will grow on “my farm”, (b) how much it will cost to grow the crop/s, (c) what are the current production levels or what crop will likely have high demand but supply shortages? Although some of this information was available from various sources it was not reaching the farmers in a way that they could act on this information to achieve their goals. Also, information about current production levels for different crops at a given time needed to be generated in real time.

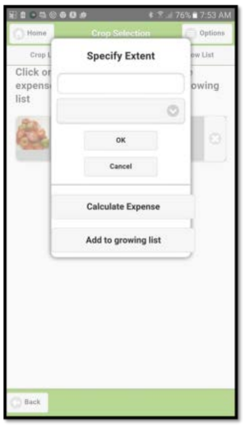
After studying the agriculture domain knowledge, an ontological knowledgebase linked to a mobile based artefact was developed to answer the question “What will grow on my farm?” [12]. When a farmer asks the question what will grow on their farm using a mobile application, the system captures the user’s geo-coordinates to obtain the farm location and map the location to corresponding agro-ecological zone using a GIS. Based on the agro-ecological zone, the system finds the climatic and soil parameters for the farm. Using this information, the ontological knowledgebase is queried to obtain list of crops that will grow on that farm. This is presented to the farmer on his/her mobile as shown in Fig. 1(b). The next question to address was: “How much it will cost to grow a crop”? To enable the question to be answered, we added expense calculator functionality to the mobile application as shown in Fig. 1(a) and Fig. 1(d). From the list of crops that will grow on the farm, a farmer can select a crop and specify the extent s/he is planning to grow as shown in Fig. 1(c). The mobile artefact then fetches the inputs required per unit area, such as fertilizer, pesticides, machinery labor, and seed required for the selected crop from the ontological knowledgebase and current market prices from another database and present the cost of production to the farmer as shown in Fig. 1(d). After exploring the cost of production for the different crops in the list of crops that will grow on the farm, the farmer can select a crop to grow and add it to a list. At this point the system captures the crop and the area that the farmer is planning to grow. Once statistically significant number of crop selections from farmers are collected, the system can start predicting the current production level thus generating the information required to answer the next question: “what is the current production levels for different crops?” The current production level information is presented to the farmer by adding a color code to list of crops; green, yellow and red for low, medium and high production levels respectively [9, 13] as shown in Fig. 1(b).

Once a Smart Computing solution was devised for an individual farmer, it was extended to connect all stakeholders of the domain to empower the society as a whole. This was achieved by enhancing the flow of information among all stakeholders in the agriculture domain enabling effective coordination of inputs such as fertilizer and pesticides, market linkages by creating a function “My offerings” in the mobile app for farmers to offer their produce to the wider community. Aggregated production data was made available to farmers through color coding and to others stakeholders via Dash Boards to take informed decisions to better coordinate the activities thus creating a Digital Knowledge Ecosystem. This is essential for the long-term stability and adaption of the system by masses as well as to reinforce the new behavior required from each of the users.

(a) Main menu



(b) Crops that will grow in "My Farm"



(c) Specifying the extent for calculating expenses

(d) Summary of costs

Fig. 1. The farmer user interface.

3 Related Work

Information and communication technologies (ICTs) have been identified as a valuable tool to tackle problems related to SDGs. In the context of this work, a number of frameworks have been developed that utilize different technologies in agriculture. AgriSuit [14] is a framework for assessment of the suitability of lands for agriculture in Ethiopia.

In AgriSuit, data is obtained from satellite data and public data sources and computed in a backend. End users access the system via a GUI optimized for access via desktops.

Yan-e [15] discusses the design of an agriculture management system based on Internet of Things (IoT). The system is organized around three key functionalities: data collection, data transmission, and data analysis. Input data is generated by a number of sensors spread around a large area. The system not only collects environmental data, but also collects data about the state of crops that are stored after harvesting processing occurs in the cloud. End users access data via mobile phones, however there is no discussion whether the system has been deployed or tested in the field.

Agri-IoT [16] is an IoT-based semantic framework for e-farming. It focuses in the capability of aggregating streams of data from different sources. Its backend comprises capabilities for real-time data analytics and reasoning. Sources of data comprises not only traditional environmental sensors and public data sources, but also cameras and drones. Output from the system include dashboards and mobile apps. There is no discussion available about deployment of the solution in production environments.

The aforementioned approaches are focused on the technological aspects of the problem with limited consideration for the end-users of such systems. So, it is difficult to evaluate the effectiveness of the approaches and the value brought for these technologies. In fact, most approaches do not consider the end user's perspective in the design stage. Our approach considers the full spectrum from underlying technology to end-users, and takes into consideration how different agents and actors are affected by the technology and how this information can be fed back to the system to enable change behavior. Without such consideration, there is a risk of failure during the adoption of platforms. Hoppen et al. [17] report on how failure in "buying-in" end-users and key stakeholders may lead to failures in project adoption. The work of Hoppen et al. [17] is particularly relevant because it reports on a framework targeting agriculture in an in-development country, as the approaches discussed so far.

Still in the topic of the importance of community involvement to enable success of ICT-based approaches for agriculture, Janssen et al. [18] presents the requirements for next generation application modeling in agriculture, covering not only technical aspects but also organizational (as in then different stakeholders that need to be involved for successful projects) and the knowledge and wisdom informing the project. This work relates to the framework we proposed, although the work by Jenssen et al. focuses on agricultural applications while our approach is intended to be of general application within SDGs.

Approaches that actually consider the end-user perspective usually target specific goals. Ag-Analytics [19] is a platform for the acquisition, storage, and analysis of data for end user researchers in the area of agricultural finance and environmental sciences. Omolayo [20] lists 10 different apps targeting issues related to agriculture in Africa. Each of these apps targets a specific aspect (such as dairy management, detection of diseases in cattle, marketplace, advise, and others), and were developed by private companies. Because most of these projects are business products, no information is available about the conceptual frameworks (if any) that drove the design and development of the apps. The exception to the above is the EZ-farm app developed by IBM Research

[21]. EZ-farm utilizes IoT to help farmers to monitor soil moisture levels and thus manage water resources. The system was deployed in Kenya.

Our framework addresses general aspects related to the management of agricultural data, geolocation, and users to enable a number of different applications, having as objective community and social empowerment with members of the communities affected by the system as the system's end users. The feasibility of the approach has been demonstrated in a previous project [4] where a Digital Knowledge Ecosystem has been deployed in Sri Lanka to empower farmers to make more economically viable decisions about what, where, and when to plan so duplication of crops is avoided, yielding greater benefits for all the farmers that utilize the system.

Finally, it is worth mentioning that similar frameworks were also proposed for different domains. Vlacheas et al. [22] discuss a framework based on cognitive management and IoT enabling Smart Cities. Bellagente et al. [23] developed a framework for energy management in smart buildings, applied on a University campus. Lu and Cecil [24] applied IoT to enhance productivity in smart manufacturing. These approaches can also benefit from the holistic perspective enabled by our work, although a level of customization would be necessary to tackle domain-specific requirements, objectives, and user needs and expectations.

4 The Proposed Framework

We used the insights gained from developing the mobile-based information system for farmers in Sri Lanka and India [4, 9, 10], discussed in Section 2, to create a generalized framework to effectively use Smart Computing to propose a multi-disciplinary solution to address SDGs targets.

The abovementioned insights have shown us the observed problems are only symptoms of a deeper problem; the root cause being coordination failure at multiple levels over a period of time compounding the problem [25]. This coordination failure is due to relevant people or domain stakeholders not having the right information at the right time to make informed decisions. This has created information asymmetry allowing people with information to create profitable operations while disempowering the others.

There have been many attempts to enhance the flow of information using mass media, radio, television, face to face workshops, call centers etc. But a solution that can reach the masses has not been found. The rapid growth of mobile devices among the affected masses now provides a personalized channel to communicate information. Even though many mobile-based applications have been developed for the agriculture domain, none of these applications has been widely adopted. Analysis of such applications revealed that these applications are providing information targeting one or few symptoms in a generic manner, but not a holistic solution addressing the root cause [26].

Using Smart Computing, we can develop artefacts; especially mobile-based information systems to enhance the flow of information in a domain. Information from sensors, both fixed and embedded in mobile devices such as GPS, can be used to identify some aspects of the context to provide personalized information addressing shortcomings in some of the earlier mobile applications providing generic information. Yet, if these applications fail to empower users and society, then they will not be adapted at large. Finally, solutions that are economical and sustainable will grow while the rest will die over time [13].

To develop a holistic sustainable solution, we need to consider it from multiple dimensions drawing on expertise from multiple discipline areas. The lack of a suitable framework to manage such complexities has hindered the development of sustainable solutions to large-scale challenges and pressing problems we face today. The ability to explore the solution from multiple dimensions and being able to integrate the insights from each dimensions to a holistic solution address this drawback. We have identified these dimensions to be Economics, Domain Knowledge, Interaction Design, User Interface Design, User Empowerment, and Societal Empowerment, as depicted in Fig. 2.

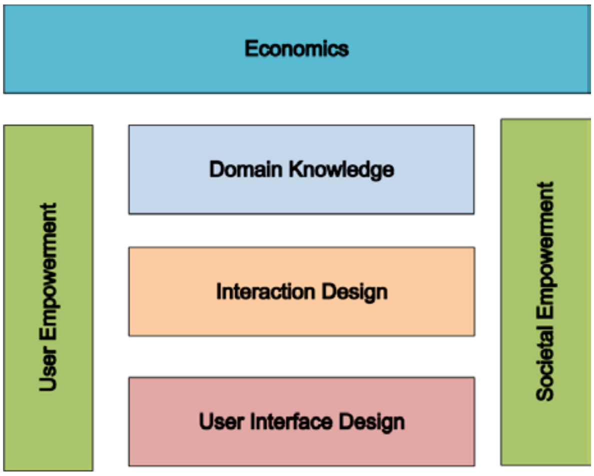


Fig. 2. The proposed framework with six dimensions

Economics: In this dimension, a root cause analysis is done to identify the fundamental problem that gives rise to the visible symptoms. Moreover, a conceptual solution should be devised to address the given problem, which will be based on user and societal empowerment. Solutions to any large complex problem fall beyond an individual and need a community approach. The community will organize themselves into horizontal and vertical value creation networks. In these networks, information, material and finances need to flow. To achieve the optimum flow there need to be coordination at multiple levels. This requires people having access to the right information at the right time to make the right decisions. The decisions should lead to optimal matching of wants and needs with the minimum search cost to achieve the best possible solution.

Issues with the flow of information affect the economic sphere. Initially, these problems can surface as health, production, nutrition, social problems etc. All these problems have a value associated with not acting or acting on them. This governs whether the investments required to fix the problem will happen or not happen.

In the case of Sri Lankan farmers, the problem was a mismatch in supply and demand leading to fluctuation of prices and intermediaries with information exploiting the situation, making excessive profit. As explained earlier, this understanding enabled us to explore possible mechanisms to better match supply and demand to solve the problem.

Thus, an analysis of the problem from an economic dimension will help in the identification of the root cause as well as conditions that need to be satisfied to address the root cause.

User Empowerment: For a solution to succeed, users need to adopt it at scale. This requires sustained user behavior change. Empowerment Theory [27-29] shows that to bring about a behavior change, we need to empower the person. People can be empowered by providing choices and other information that can help them to achieve goals meaningful to the individual. Thus, in this dimension we need to identify goals meaningful to the potential users and identify a set of process that will assist them to achieve these goals. Further, these processes were embedded with choices, supported with relevant, accurate and timely knowledge, to enable informed decisions.

In the case of both Sri Lankan and Indian farmers, their goal was to increase their incomes. This requires minimizing the cost of inputs required for production and maximizing the selling price. Farmers want to have a prediction of the final potential sale price at harvest when they make decisions. At the time, they had no way to accurately predict the potential selling price. As the price is a function of supply and demand, expense calculations and price predictions were incorporated into the application to assist them to achieve their personalized goals.

Thus, in this dimension, relationship between conditions that needs to be met for the solution to be economical and sustainable and individual user goals are identified. From this, functions and information needs for the users to better achieve their personalized goals can be derived.

Societal Empowerment: As mentioned earlier, the root cause for many of the major problems facing the society is coordination failure at multiple levels. Thus, when formulating a solution, in this dimension we need to examine how the developed solution can lead to enhanced coordination of the activities for all domain stakeholders or the community to achieve an enhanced value from their efforts.

In the case of Sri Lankan and Indian farmers, they were buying production inputs at a higher price from retailers and selling the harvest at wholesale prices to vendors who buy in bulk. This is a very unfavorable situation for the farmers, who are squeezed form both agents. When they used the mobile app to calculate the cost of production, they were able to calculate the fertilizer and pesticide requirements and cost. The system was able to aggregate farmer input needs for a given geographical area. This enabled farmers to buy their inputs at a wholesale price. This information enabled them to effectively coordinate the transportation of inputs, further reducing the cost of inputs. In addition, they were able to aggregate the harvest and sell to larger buyers at a higher price than what they were getting before. Therefore, coordination and aggregation led to societal empowerment.

Thus, dimension studies how best to coordinate the various related activities to achieve a better outcome due to new ways available for individuals to make decisions and due to the mobile system's availability to support this behavior.

Domain Knowledge: Having understood where critical coordination failure has happened and the economic dimensions of the problem, it is then necessary to identify how the various tasks are carried out in the application domain and what information is required to make optimal decisions to achieve better coordination. Domain experts are needed to advise on various aspects of the solution and provide relevant discipline-specific information. In general, we found the needed information could be divided into two categories: (i) quasi static – information that can be derived from published literature and only changing periodically; and (ii) dynamic or real time – information changing rapidly such as current production levels that needs to be generated in real time.

In case of Sri Lankan farmers, they wanted to know what crops they could grow on their farm based on the climatic and soil conditions and what the current production levels were to avoid market saturation.

Thus, in this dimension, how the activities in application domain is happening and what new scenarios are possible is studied.

Interaction Design: This is the dimension that has been revolutionized by Smart Computing. In this dimension, we need to identify ways in which users can interact with information. This is best explained using the evolution of GPS as an example. Before GPS, people used printed maps to go to places. The maps were useful, but not very easy to use while driving a vehicle and not many people new how to effectively use a map. The early GPS contained the same information that was in a printed map but now in a vector form. Once the destination was keyed in, it was able to work out a suitable route and at various junctions was able to inform the user to turn left or right or go straight. We can visualize the GPS as a multi-layer device; at the bottom layer is the printed map converted to a set of spatial vectors. The next layer is the smart sensor layer that senses the user's location is real time and generates actionable information by reading the vector information that match with location data in the form of next action to be performed. This change in interaction enabled more people to navigate using GPS compared to a printed map.

When more people start using GPS for navigation, the capabilities of the GPS got further enhanced. Using sensors, it was possible to find out the time it took to a user to travel a specific road segment. Thus, a third layer was added to the GPS, which is real time traffic map. Now, the actionable information that is generated at each junction not only looks at the shortest distance to the location; but also determines the route to get to the location in the shortest possible time.

In the case of Sri Lankan farmers, the interactions were designed in a way they can ask what crops will grow on their farm using a mobile phone, which will also provide the geo-coordinates. Thus using a GIS system, the corresponding agro-ecological zone together with climatic and soil parameters were obtained. This is similar to the second layer of the GPS example of identifying the current context using Smart Sensors. Published crop information was organized into an ontological knowledgebase so that it could be queried based on climate and soil parameters to generate a list of crops that will grow on that farm and provided to the farmers to make a choice of crops. This is similar to the first layer of GPS example.

In the Domain Knowledge dimension, we investigate how activities happen. It was found that farmers look at the cost of production when making a decision among available choices. For this purpose, an expense calculator was provided. When farmers enter the planned area for planting, the system can find the required amounts of fertilizer, pesticides and other inputs for the selected crop and display this information to the farmer. This helps farmers to make informed decisions. The system collects this information and uses it to generate more targeted actionable information. This is similar to third layer of the GPS example.

Thus in this dimension making use of Smart Computing capabilities, the optimal way for a user to interact with information is worked out. The approach is to explore the optimal way to present the quasi static information needs and get users to interact with this information in a way to generate the dynamic or real time information needed to achieve optimal coordination.

User Interface Design: This is another dimension that requires a different set of expertise. The flow of information from the system to user and vice versa happens through the user interface. These interfaces could be textual, visual or graphical and auditory. The design of the interface needs to take in to account the language, culture, and literacy and education level of the users, among other things.

In the mobile system that was developed for the Sri Lankan and Indian farmers, the user interfaces evolved through an iterative process. We observed how they used the first prototype and identified the areas where they had difficulty. These were addressed based on HCI principles and the next prototype was given to them. At this stage not all interfaces were implemented in the mobile; some were presented as paper passed print outs. This, although happened due to lack of time to complete the prototype prior to field visit, turned out to be very useful. Farmers started to annotate the paper prototype with their ideas, making the process truly participatory [9]. This method then became the standard until we arrived at the final set of user interfaces shown in Fig. 1.

Thus analyzing and finding solutions to the problem in these six dimensions will result a holistic solution. It may appear that the activities in each of the dimensions tend to follow a sequential order, but this is not the case. They can happen in parallel or in any order depending on the problem and the skills of the team members applying the framework.

5 Case Study: Mitigation of Hidden Hunger

As the conceptualization of the framework discussed in the previous section occurred concurrently to the development of the solutions described, a question arises on the reproducibility of the results and generality of the framework to solve problems in different domains for SDGs. In this section, we describe our experience applying the framework in the domain of hidden hunger in African countries, which in turn demonstrates the generality and broader applicability of the proposed framework.

Hidden Hunger is a challenging health and wellbeing issue in Africa where the population do not get enough nutrients in their daily diet. Sub-Saharan Africa has one of the highest levels of child malnutrition globally and it has been estimated that 39% of children in East Africa, 32% in West Africa and 28% in Central Africa are stunted (short for their age) [30]. These statistics reflect a state of undernourishment in early life and leads to irrecoverable physical and mental development problems. Overcoming micronutrient deficiencies requires the diversification of diets and an increase in the consumption of micronutrient-rich foods.

5.1 Framework Adoption

We investigated a solution to overcome this problem within a multidisciplinary team to understand the root cause and possible solutions. We present our investigation in the context of the proposed framework as follows:

Economics: The root cause of the hidden hunger is not getting enough nutrients, while generally having enough daily intake of calories. This comes from the lack of food diversity. In many areas, there are highly nutritious indigenous foods that can be grown, but information on these crops and their nutritional value is not readily accessible. The conceptual solution is based on increasing awareness about hidden hunger and providing information and knowledge for sustainable access to diverse food sources including growing local crops and trade foods within the local communities.

User Empowerment: While improving the health and wellbeing was the immediate goal of decreasing hidden hunger, access to food and affordability are primary user concerns. The health-promoting benefits of eating these foods could be a second interest to the users. The proposed solution was based on a research, showed that household production of fruit and vegetables could reduce the incidence of hidden hunger in South Africa [31]. The project developed an application for the selection of diverse crops that could address hidden hunger. This approach is referred to as nutrition- driven agriculture.

Societal Empowerment: Nutrition-driven agriculture could be more effective if the community were empowered to take advantage of sharing and trading more nourishing products and creating more awareness around hidden hunger. We extended the current solution to a social network where individuals can get information about available nutritious foods and products in their local area and be able to have more sustainable and affordable food access. This brings more sustainability in terms of motivation and scalability to the proposed solution and can be adapted by similar cases in other countries.

Domain Knowledge: The proposed solution needed expertise in the area of food, nutrition and agriculture to provide relevant information to address the issue. This information includes available local crops suitable for a specific agriculture/geographical zones as well as nutrition information about the foods. Having this information, the solution can recommend what crops can grow to address nutrient deficiencies.

Interaction Design: In this dimension, we need to devise a workflow to interact with users. Based on the domain knowledge results, we developed a dietary diversity survey for users so they enter their intake for last 24-hours [32]. The data were classified into 16-food categories. Where the diet was deficient in some of the food groups, the application identified crops that could grow in that area that could fill this gap. We used mobile information to identify the user location. Given the societal empowerment requirements, we plan to develop an optimizer to maximize the food diversity within the community by proposing various crops.

User Interface Design: Given the low level of literacy and education in many rural communities in Africa, we designed a visual food survey as well as graphical navigation tools to develop the solution. The developed application is a mobile app with a graphical user interface where users can see the pictures and select their intake. They are able to see the list of local crops and recommended crops with the relevant pictures.

5.2 System Prototype

In this section, we present the detail of the system prototype, which was developed based on the proposed solution in six dimensions. Figure 3 shows the workflow of the system prototype. We designed the workflow at household level where users will provide information about their household diet as the main input. We collect the dietary survey information from users and identify the missing food groups. Then we create a mapping table to identify the list of crops that grow in the user location that can address the dietary deficiency. The list of crops along with relevant information is provided to users. This provides enough options for users to select appropriate crops to grow based on their requirements and available resources.

The system prototype has been developed as a mobile app for Android devices with relevant information about three countries (Kenya, Nigeria and South Africa). Users are able to register to the application, providing their location and personal information, including the number of people in the household. The survey is conducted at the household level and users can select the foods that have been consumed by the household members in the last 24 hours using a visual interface as shown in Fig. 4. After completion of the survey, the results tables show food categories that are missing in their diet. Users are able to see the result of last survey including date and the missing food groups. This is part of user empowerment to increase their knowledge about their food habit.

Users can continue their navigation through the app and access the recommended crops based on the missing food groups as shown in Fig. 5. Information about each crop, including season and production guidelines are provided to users. The system prototype also has a data analytics backend where researchers are able to look at the

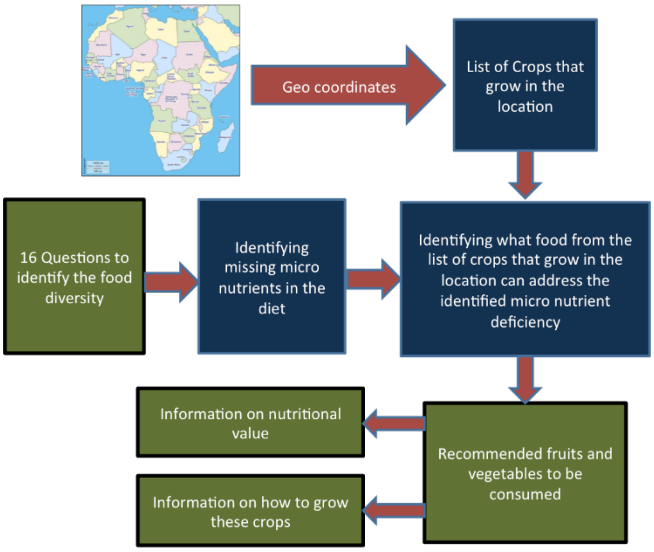


Fig. 3. The workflow of the system prototype.

various data with various filtering including date, food groups, and geographical region. In addition, there is user management option for the administrator to manage registered users.

6 Evaluation and Discussions

We asked the question whether the proposed Smart Computing framework could address problems beyond the domain that motivated its development. In order to answer this, we applied the same conceptual framework to address hidden hunger at the household level in Africa. In this section, we aim to answer if it achieves its objectives of enabling end-user empowerment and achieving SDGs.

To carry out this evaluation, we look at two important aspects: its effectiveness in solving the target problem and its effectiveness in promoting change behavior in end users. It takes a long time in this type of project to measure the actual economic and social impacts. But what is essential to take place, and measurable in shorter timespans, is the change in user behavior.

6.1 Addressing the hidden hunger issue

The first aspect that requires investigation is the effectiveness of the solution in solving the problem that triggers the application of the framework. In this example, the problem was hidden hunger, and thus the question to be answered is: does the system prototype, which has been developed following the proposed smart computing framework, have the potential to address the hidden hunger problem? To answer the question, we employed a team of experts in the relevant domains to provide feedback on the features of the app and their perceived value and effectiveness.

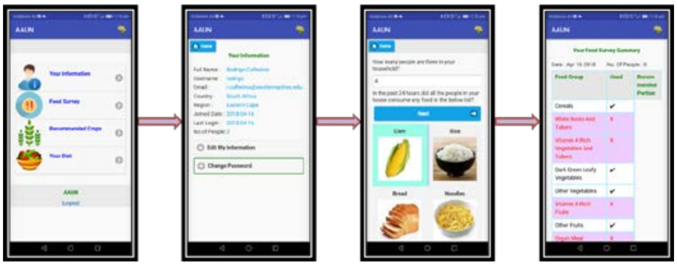


Fig. 4. Food survey.

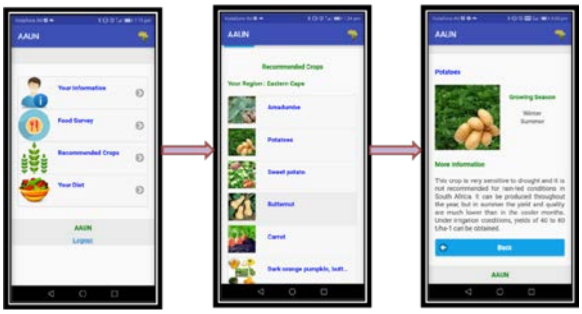


Fig. 5. Crops information.

Experts included several food and nutrition scientists as well as two crop scientists. Feedback from crop scientists was to expand the amount of practical crops covered in the survey and to remove exotic foods and vegetables as well as narrow down recommended crops to take into consideration the microclimate of the users. This way, not only geolocation but also maximum temperature, rainfall, seasonality, and frost issues are taken into consideration when crops are suggested. Other feedback from crop scientists were more of a general nature – provide nutritional information delivered by each food group and more information about the household member filling the survey (e.g., age, gender).
The food and nutrition scientists provided feedback concerning expanding the app capabilities to provide direct access to the recommended crops (for example, by directly linking the app to online markets); include insects in the food survey; enable the capture of seasonal behavior (harvest time and between-harvest time); include more details in recommended crops (including cost and time to grow). The market capabilities in the app and seasonality in user behavior are interesting aspects to be explored in future works. To ease addition of information of crops, backend functionality has been added to assert that databases and user interfaces are completely separated from the underlying data that can be made available.

Finally, another feedback from the food scientists was enabling a social network to expand the reach of the application. In fact, we had this feature as part of the framework, but this feature needed to be delayed because it is a complex functionality that depended strongly in user adoption to succeed. Thus, it was a logical decision to focus initially in singular users (users and households) and, if the app succeeded at this point, expand it to community level. The positive reaction of end users to the app (described in the next section) provided the motivation for prioritizing this feature in next development cycles, and the feedback from the food scientists gives us confidence that the time and cost for developing this feature is well-justified.

In summary, expert feedback provided us insights that we were in the right direction in the early prototype, although adjustments were needed to better reflect the particular food habits of the target groups and to maximize the amount of valuable information provided by the app. However, the most decisive factor in the success of the app lies in end users adopting and benefitting from the app, which is discussed in the following section.

6.2 Promoting behavior changing in end users

Effectiveness of the framework in promoting change behavior in end users is affected by a number of reasons. First, as reported by Hoppen et al. [17], there is the problem of convincing end-users of the relevance of the problem and the solution, as this will result in the end-user buy-in necessary for initial adoption of the solution. Second, the initial buy-in is not enough to guarantee that the objectives are met. As discussed in Section 4, even if end-users are willing to adopt the solution, but the solution fails in empowering them, the solution is also likely to fail. We therefore evaluated the point where the proposed framework interfaces with end-users: the prototype mobile app.

Usability study of the mobile app has been carried out at the Department of Informatics at University of Pretoria, South Africa [33]. Six end-users (workers from the experimental farm of the University of Pretoria) participated in the study. There was equal representation of men and women in the observed group. Their ages ranged from 25 to 50 years. Participants were asked to carry out certain activities in the app and the effectiveness was observed in terms of which tasks they were able to complete. The tasks participants completed were:

- Start the app and complete registration
- Change location in their user profile
- Complete the 24 hours recall food survey
- Analyze the summary provided after survey completion
- Analyze the “recommended crops” portion of the app
- Explain the information presented in the household diet

This initial evaluation provided some insights in minor language localization issues and other minor usability issues. For example, utilization of pre-filled forms confused some users while others had difficulty with the fact that the virtual keyboard of the phone covered part of the app screen.

Another aspect that required improvements was the mapping of the original paper-based questionnaire to the app: the original questionnaire only asks if at least one food of a given group was consumed or not; there was no need to record how many food items (and which ones) were consumed from the group. The first version of the app reproduces this concept by progressing to the next food group once one food of the group was selected. However, during the evaluation, users were confused about this feature, and thus the design was changed so users can record all the consumed foods of a given group. Likewise, a majority of usability-related issues and feedback were addressed in the second development cycle of the app.

Overall, the app has been positively received by the users, which provided information about extra features they would like to see in future versions of the app. This is a great example of valuable feedback from end-users: they see value in the app as is, and they signaled other types of information that they currently miss and that they see as relevant to help them improve their diet. Some of the extra information they see as valuable include information on how to prepare meals with the recommended crops, which crops are easier to grow, information on fertilizers and pesticides, and even a section with tips for healthy living (for example, exercising).

A particular evidence of relevance of the app for end users came from one of the users that, while carrying out the usability test, reached the crop information about potatoes and realized that the method he was utilizing was incorrect, thus impairing his efforts. The usability test allowed him to benefit from the knowledge enabled by the app, and led to the user to change the way he grows his crops, an information that, although seems trivial, was not easily available to these farmers.

These results further validate findings from the project in Sri Lanka: the main issue faced by rural communities, and that hinders a better lifestyle for them, is lack of basic information. Our Smart Computing framework is a step towards better and timely availability of information for end-users, what can be a powerful tool for their empowerment and solution of SDGs.

7 Conclusions and Future Work

In this paper, a smart computing framework based on user and societal empowerment is proposed. This framework has six dimensions and was created based on series of previous experiences to address SDGs. In order to show the applicability of the proposed framework, a case study to address the hidden hunger issue in Africa was presented. Having the framework to guide the thinking and designing of the solution helped us to frame a holistic solution centered on user and societal empowerment. The system prototype and its evaluation also presented and revealed that this framework can be adopted to develop effective and innovative solutions to address other SDGs.

As future work, we intend to develop the hidden hunger application further and add social computing components to complete the societal empowerment. Evaluation by testing the application in different communities across African countries is also part of our future plan. We also would like to adopt this framework for other SDGs and refine the framework further.

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