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Infant's Growth and Nutrition Monitoring System

Homa Radgohar*, Hamed Vahdat-Nejad*, Saber Mohammadzadeh Rezaie **

* Perlab, Faculty of Electrical and Computer Engineering, University of Birjand, Iran

** Iranian Society of Pediatrics, Birjand University of Medical Sciences

Radgohar.homa@birjand.ac.ir , vahdatnejad@birjand.ac.ir , SaberMohammadzadehR@bums.ac.ir

Abstract

Infants health plays a major role in the development and healthiness of the future society. With the development of ICT and the advent and growing popularity of smartphones, there has been an opportunity to make changes in children health services. In this regard, many applications have been developed, most of which have not been designed according to scientific medical references or under the surveillance of physicians. Therefore, they are not popular among parents and the medical community. Moreover, these systems are not enough comprehensive to meet all of parental needs in taking care of children. In this paper, a context-aware infant growth and nutrition monitoring system is proposed, designed, and developed under a pediatrician's supervision. In this regard, the latest medical references have been taken into account. The proposed system has the growth and nutrition monitoring, health monitoring, and doctor intervention functionalities. It is implemented by Android on smartphones, then the SAAM scenario-based method is used to evaluate it. Finally, it is compared with other related systems. According to the comparison results, the proposed system provides more comprehensive and extensive features and capabilities, which meet parental needs in taking care of children.

Key words: Infant's growth and nutrition, cloud computing, smartphone, Software engineering, Pervasive computing

1. Introduction

Children are the future of the human society; therefore, their appropriate growth is important. In this regard, the experts concentrate on the early years of life as a golden age [1] and believe that it is the ideal time when children form their future habits[2]. Thus, infants growth should be monitored to detect and modify any deviations from appropriate growth. Growth refers to specific body changes and increases in the child's size including such as height, weight, head circumference, and body mass index. These changes can be easily measured. The sequence is basically the same for all children, however the rate varies.

One of the important tools used to follow child growth is growth monitoring, which determines the desirability of child growth with relevant criteria and standards by making comparisons[3]. The main aim of growth monitoring is the early detection of growth disorders[4]. Various factors can result in deviation from the desirable growth. The most important factor is nutrition, which provides the necessary energy for different activities and helps the body to prevent from diseases[5]. It can also prevent the prevalence of chronic diseases or reduce their intensity[6]. Nearly 25% to 50% of infants have nutritional disorders. In this regard, there are some concerns about low weight gain, obesity, essential nutrient deficiency, and poor dietary variety[7]. According to previous studies, the majority of mothers don't have the necessary knowledge about the appropriate nutrition for their children[8].

Pathogens are another important factors influencing a child's growth. The health and regular vaccination can immunize a child's body against pathogens. However, some mothers have difficulty remembering the vaccination dates of their children[9], but some others do not have enough information about necessary care for the prevention of diseases or childcare at the time of a disease.

IT developments as well as the penetration of mobile devices have made some changes in medical and health services. The ubiquity of mobile devices in daily life has resulted in the opportunity to improve information access. Mobile devices such as smartphones and tablets have overcome the portability constraint of fixed computer systems and provide access to health data anywhere at any time[10]. Therefore, nowadays mobile devices, especially smartphones, have become a popular and powerful platform for developing viewpoints based on mobile health[11]. Mobile health (m-health) services lead to the early prediction and management of every abnormality

or disorder[12][13]. In addition, using pervasive computing in healthcare systems reduces costs and improves services for patients and provides them in anytime and anywhere manner. Besides, doctors and nurses become enabled to monitor and take care of patients anywhere at any time[14]. In pervasive computing, applications match their behaviors with context information and act, accordingly[15]. Context is a type of information that can be used to characterize the situation of an entity (such as a person, place or object)[16]. Combining m-health services with context-awareness increases their usefulness and popularity[17]. However, mobile devices suffer from memory shortage and low computing powers; they have difficulty running huge software[18]. Transferring all or part of the processes and storage operations to the cloud can be an appropriate solution to this problem[19]. Actually, the advantages of cloud computing such as platform flexibility, interoperability, and on-demand services have made it the perfect solution for data integration as well as pervasive health monitoring[20]. Leveraging new technologies in childcare can have a significant effect on their appropriate growth. In the past, several studies have intended to present m-health systems in childcare. However, the majority of them are not based on state-of-the-art scientific references; therefore, parents and doctors have not found them reliable enough. Moreover, the majority of designed systems do not meet all parental needs in a way that they have to use several applications simultaneously to take care of their children. The aim of this research, which is conducted under a pediatrician's supervision and by consulting newest scientific references in this area [3, 21-23] is to leverage pervasive computing in designing a context-aware mobile-based system to monitor child growth. The proposed system consists of parental as well as physician side providing three major functionalities of child growth and nutrition monitoring, child health monitoring, and doctor intervention capabilities. The context-awareness technology is used to make the system intelligent and predictive so that suitable services can be provided by modeling current situation. Furthermore, the cloud is employed to resolve the low computing power and storage shortage issues of smartphones.

The proposed Pervasive Infant's Growth monitoring (PIG) system is implemented by Java-based Android programming language [24] for Android-based mobile phones. It is evaluated using the scenario-based method. The results indicate that the PIG is more comprehensive than other similar systems and bears more functional capabilities. When it is used, the infant's pediatrician is become aware of child's growth and the system functionality.

After this introduction, the next section reviews previous research on growth monitoring, childcare, and child nutrition. In the third section, various scenarios are presented to investigate the system requirements. The fourth section describes the architecture of the proposed PIG system. Afterward, the system is evaluated, and the results are analyzed in section 5. Finally, section 6 expresses the conclusion remarks and discusses the future research directions.

2. Related work

In the past decade, the advent of m-health resulted in many studies and applications. Infant's care is regarded as a branch of m-health. Based on the purpose and area of study, children healthcare systems can be classified into growth monitoring, child healthcare, nutrition monitoring and hybrid systems. The studies of each class are reviewed in the following.

2-1. Growth monitoring systems

Monitoring growth continuously and detecting poor growth quickly are the important actions that should be taken to control a child's health. In 2013, a mobile application named "healthy infant weight?"[25]was introduced. It predicts the risk of obesity in babies aged between 0 and 2 years old. In another study[10], a mobile application is presented to detect obesity in people aged between 2 and 24 years old with respect to Body Mass Index (BMI).

Furthermore, there are other applications including "Baby Growth Chart"[26], which is mainly intended to draw growth charts. The application "Growth Chart CDC WHO Percentile"[27] has been designed to draw the growth chart based on the standards issued by World Health Organization (WHO) and Center for Disease Control and prevention (CDC). Other similar applications are "Growth Chart Pro"[28] and "Growth: Charts For Baby And Child Tracking"[29].

2-2. Child healthcare systems

Since a disease can disrupt a child's appropriate growth and weight gain, some studies have sought to design a system to remind the vaccination time and provide necessary healthcare trainings at the time of a disease. For instance, an application named MTika[9] has been developed to provide vaccination time reminders for babies

aged between 0 and 11 months old in remote and low-income urban areas. The aim of this application is to create a mechanism to improve children vaccination status in Bangladesh's public health system.

The application of "Pediatrician"[30] explains prevalent childhood diseases with their treatment methods. Other similar applications are "Save The Date To Vaccinate"[31] and "Vaccination Reminder"[32].

2.3- Nutrition monitoring systems

Nutrition is the most important factor in a child's growth. It provides a child with the necessary energy to grow up. In 2014 [1], a system has been designed to enable parents to determine appropriate nutrition for their child based on age, food allergies, and food suitability. In another work[33], a mobile application has been presented to control the weights of children with obesity. It recommends a diet based on the user profile including age, weight, height, necessary energy, and activity. In "Tell Me What to Eat" project[34], another mobile application has been designed to improve nutrition consumption in obese children. It presents a list of appropriate dishes with recipes based on the available nutrients and user preferences. In another study[8], a diet management system has been proposed in India to provide children with food menus. This system uses a data mining method to recommend an appropriate diet. In addition, there are other applications for children nutrition such as "Child Foods and Nutrition"[35], "Baby Food Recipes"[36], and "Baby Food"[37].

2.4- Hybrid systems

Some systems present a hybrid of above functionalities. In 2016, a diet recommender system has been introduced for obesity management[12]. Basic information (e.g. sexuality, age, BMI, etc.), medical information and environmental data (e.g. time, temperature, season, humidity, etc.) are taken into account to recommend top recipes and menus to users.

In "Child Growth Mentor"[38], a mobile system has been designed to monitor a child's growth. It also reminds users of the vaccination time (date and type of vaccination). Moreover, it presents nutrients and recipes with respect to the child's age and favorites. It also suggests papers on child development and age-appropriate puzzles and games.

Another similar application is "Baby Care-tracking growth"[39], which records height, weight, and head circumference, reminds vaccination dates, and shows tooth health and tooth development phases. The "Baby Complete Guide"[40] presents grow and health services, infant nutrition, games, useful activities, and recipes for appropriate infants foods. It also receives parent's questions and answers them by its experts and lets users see the latest questions and answers raised by other users. In addition, it provides parents the latest recommendations by advisors. The application of "Baby Care, Baby Recipes, Tracking" [41] introduces recipes and draws the growth chart. Other similar applications include "Baby Growth Chart & Complementary Foods"[42] and "Monthly Baby Growth"[43].

Generally, there has not been a system yet to monitor a child's growth, comprehensively. There are a few studies and applications that consider children's growth, health and nutrition monitoring, simultaneously. On the other hand, the majority of designed systems in growth monitoring only show the position of a child on the growth chart. They do not analyze the growth. However, some parents have difficulty understanding growth charts. Moreover, when a diet is recommended, it is necessary to evaluate the child's growth status including obesity, underweight, risk of weight problems, and health status.

Most of the market applications suffer from scientific contents. In fact, their commercial features have been paid more attention and in designing them there have not been a scientific viewpoint. Such applications must be developed and evaluated with the cooperation of pediatrician, parents, and IT experts. Moreover, only a few of them are useful for children by meeting their main demands and needs. To develop a scientific and appropriate system for monitoring children's growth, all system requirements should be specified under a doctor's supervision.

The proposed system considers growth, nutrition and health. Regarding growth, it interprets a child's growth status in addition to showing the child's position on the growth chart. At the time of diet recommendation, it also considers the child's health and growth status. Furthermore, a doctor can receive growth data and chart to become aware of the growth process and make necessary recommendations to parents. Context awareness is leveraged to

improve the quality of services provided by the proposed system. In fact, by modeling and knowing current status of the infant, the system presents improved services. Considering the fact that smartphones have limited memories and computing powers, the cloud is used as the backend and support in the proposed system.

3. System Requirements

Pervasive healthcare is intended to provide healthcare services anywhere at any time[44]. Nowadays mobile applications have evolved quickly to be used in pervasive healthcare systems. The research problem is to design a child growth monitoring system that can help parents to take care of and grow their children. To design the system architecture, the first step in software engineering is to identify the requirements. For this purpose, the specialized references[3, 22] and pediatricians' consultations are used. Then three scenarios are employed to specify explicitly the main system functionalities.

Scenario 1- Child growth and nutrition monitoring "*Alice has an eight-month-old baby. Since she works outside, she has not been able to visit child growth monitoring and health centers, on time. On the other hand, she does not know how to use and interpret the child growth card; therefore, she evaluates her child's growth status by judging from the baby's appearance as well as comparing him to other peers The available applications used for drawing the child growth chart could not even help her because they only show the child's position on the growth chart without clarifying its concept. Besides, upon getting the age of seven months and the use of supplementary foods, Alice felt she has many questions about how to feed her baby, what to feed him, how to prepare the food, and what ingredients she should use. She did not know how to preserve the surplus food, how to detect food allergies, how to be ensured of the sufficiency of the food, what foods to use at the time of diseases (such as fevers and colds), etc. She sought the answers to these questions by asking her friends and relatives. After a while, she noticed that her baby's skin turned red with a fever. After seeing a doctor, it turned out that her baby got allergies and food poisoning due to the use of inappropriate foods. Moreover, since Alice did not know that she should give her baby more liquids to drink at the time of a fever, her baby lost too much water. When the child's growth was monitored, it turned out that the baby's weight was not appropriate. Since Alice has not evaluated her baby's weight regularly, it was not clear whether the baby suffered from weight deficiency due to the current disease or he had been affected by malnutrition before.*"

The growth and nutrition monitoring scenario shows some of the problems that most parents face. These problems can be stated as follows:

- Lack of knowledge about monitoring the child's growth, measuring weight, height, head circumference, using growth charts, and interpreting them.
- Lack of knowledge about beginning to use Complementary foods, the processes of preparing and preserving them, age-appropriate foods for the child, and suitable nutrition in general.
- Lack of knowledge about nutrition at the disease time.
- The need to communicate with a doctor or specialist to get their answers and resolve parental concerns

Given the abovementioned problems, a system is required to draw and interpret growth charts for parents and show them the growth status. This system should also be able to recommend the child's diet, an allowed food guidance, and recipes according to age, growth status, and health status. It should also provide instructions on the child's nutrition including food preservation and food allergy symptoms. When a child grows, parents face many questions. A doctor can provide parents with the best answers. Therefore, the proposed system should be able to enable the doctor to ask and answer questions. Accordingly, it should be capable of monitoring the child's growth and nutrition, something which includes four sub-functionalities. The sub-functionality of "*growth monitoring*" provides the ability to monitor the child's growth. The sub-functionality of "*growth monitoring by the doctor*" enables the doctor to monitor the child's growth status. The sub-functionality of "*nutrition monitoring*" provides a comprehensive nutrition guide to the parents. Finally, the sub-functionality of "*consultation to doctor*" allows the doctor and parents to interact with each other.

Scenario 2- Child health monitoring

"At Dr. James's clinic, Alice and Julia are speaking about their experiences of their child's disease. Julia has a six-years-old child. She said that everything was normal and ideal at birth. Her child has gained high levels of growth charts. The child did not have any delay in crawling and walking. He even made sounds until the age of two. However, the child became indifferent to others around the age of one and did not pay attention to others

when they called. He frequently cried and chose only one doll out of all the toys and did repeated actions with it. Finally, at the age of three, Julia got suspicious about these conditions when she realized that the child has delayed speaking. After seeing a specialist, she found out that her child had autism. Since she did not believe it, she decided to see other doctors and even psychologists. Finally, all of her efforts led to autism. These referrals delayed the process of treating the child, which was a loss. . Early detection could help much in treating the patients with autism. In fact, being present in the society with normal peers could help to improve the child's behavior and have great effects on the treatment. With this delay, Julia's child has lost the chance to go to normal schools and be with normal peers, in practice.

Alice also comes to see the doctor because of her child's disease. She says that her child had a high fever. She tried to alleviate the fever with some actions such as taking off the child's clothes and moderating the home temperature. However, the fever did not decrease. Then she realized red spots on her child's body. After seeing a doctor, she understood that her child had a Scarlet fever. The disease got severer and the treatment process became harder because she forgot the vaccination periods."

Given this scenario, the issues can be discussed as follows:

- Lack of knowledge about prevalent diseases in children, symptoms, treatment methods, and necessary healthcare measures taken by parents.
- Lack of knowledge about the risk symptoms indicating an urgent referral to a doctor.
- Lack of knowledge about the development phases of the child's skills and abilities.
- Forgetting the child's vaccination time.

The proposed system should enable parents to monitor the child's health. This functionality has four sub-functionalities including "prevalent diseases guide" and "red flags guide" to make parents aware of prevalent diseases and risk symptoms, "growth guide" to inform parents of the development phases of their children, and "vaccination reminder".

Scenario 3- Doctor intervention

"In a conference, Dr. James and Dr. Parker, two pediatricians, meet each other. while talking to each other about their problems, they realize that their patients suffer from some common problems despite the fact that these two doctors live and work in different cities. They find out that most of these issues are caused by parental unawareness about how to grow and take care of children. Parents do not use valid and accurate instructions and references. For instance, the doctors often deal with the children who suffer from food poisoning due to parental unawareness about nutrition. There are other children suffering from seizures or severe dehydration because of parental negligence to the symptoms as well as arbitrary treatments. Therefore, both of the doctors seek a solution to this problem. For this purpose, they decide to employ a mobile application to instruct parents. Both of them provide the developer with necessary information on prevalent diseases of children and nutrition.

After the application is developed and published, Dr. James realize some problems. Since the disease information is collected by Dr. Parker, the prevalent diseases in Dr. James's area are not observed. Instead, part of the information is about the diseases that are not prevalent where Dr. James lives. Therefore, the disease section could not have an appropriate performance for him. On the other hand, the nutrition information is collected by Dr. James; however, some of the nutrients are not available where Dr. Parker lives. In fact, they are local foods of the Dr. James living area. As a result, the nutrition section could not provide Dr. Parker with the best performance."

According to this scenario, the following requirements are discussed:

- The need to create an environment with dedicated data of each doctor
- The need to change data required by parents by the doctor

Therefore, the system should have the "doctor intervention" functionality, according to which each doctor is able to localize or update the data used by the system on the parental side. The sub-functionality of "update information" refers to this important issue.

In addition, due to the diverse use of mobile devices and smartphones, these devices have become an appropriate platform to provide services, such as healthcare. Mobility, quick initialization, and low prices are among the advantages of such devices resulting in the extensive popularity [6]. As a result, the implementation of the

proposed system on mobile devices can have a great impact on the popularity and success of this system. On the other hand, since the majority of mobile devices are based on Android, the proposed system is developed by Android.

4. Architecture design of the proposed PIG system

The Attribute-Driven Design (ADD) method is employed to design the architecture of the proposed Pervasive Infant's Growth and nutrition monitoring (PIG) system. ADD is an iterative method, which is intended to select a part of the system for design in each phase. Then it creates a design for that part and tests it. This process is continued until an appropriate architecture is achieved. The ADD method receives the system requirements including functional requirements, quality attributes, and system constraints as the inputs. The output includes a group of architectural views such as elements and their relationships[45]. The following phases are exploited to design the proposed system:

In the first phase, the main system elements are specified. The general schema of the PIG system consists of three main sections including parents, doctor and cloud. The parents and doctor sections interact each other through the cloud. In addition, the cloud is used as a storage space in which user information is stored. Therefore, the cloud supports the system so that users can retrieve the information in case of any failure in mobile devices. Moreover, the cloud provides a dedicated environment for each doctor and his patients so that they can interact with each other. This environment is separated from other doctors' environments. For instance, new data of each update is transferred to the device of the parents who are under the supervision of the same doctor, while other parents' data is unchanged.

In the next phase, the patterns are used to make a design decision. Architectural patterns form a package of decisions, which are frequently used in practice[45]. Since the proposed system is physically located in three separate areas, it includes the cloud, parental side, and the doctor's side. Therefore, the multi-tier pattern [45] is used to design it. In the multi-tier pattern, the system execution structures are organized as a set of logical groups of components. Each group is known as a tier. The general architecture of the proposed system consists of three tiers, including doctor, parent, and cloud. Figure1 shows the general architecture of the proposed system.

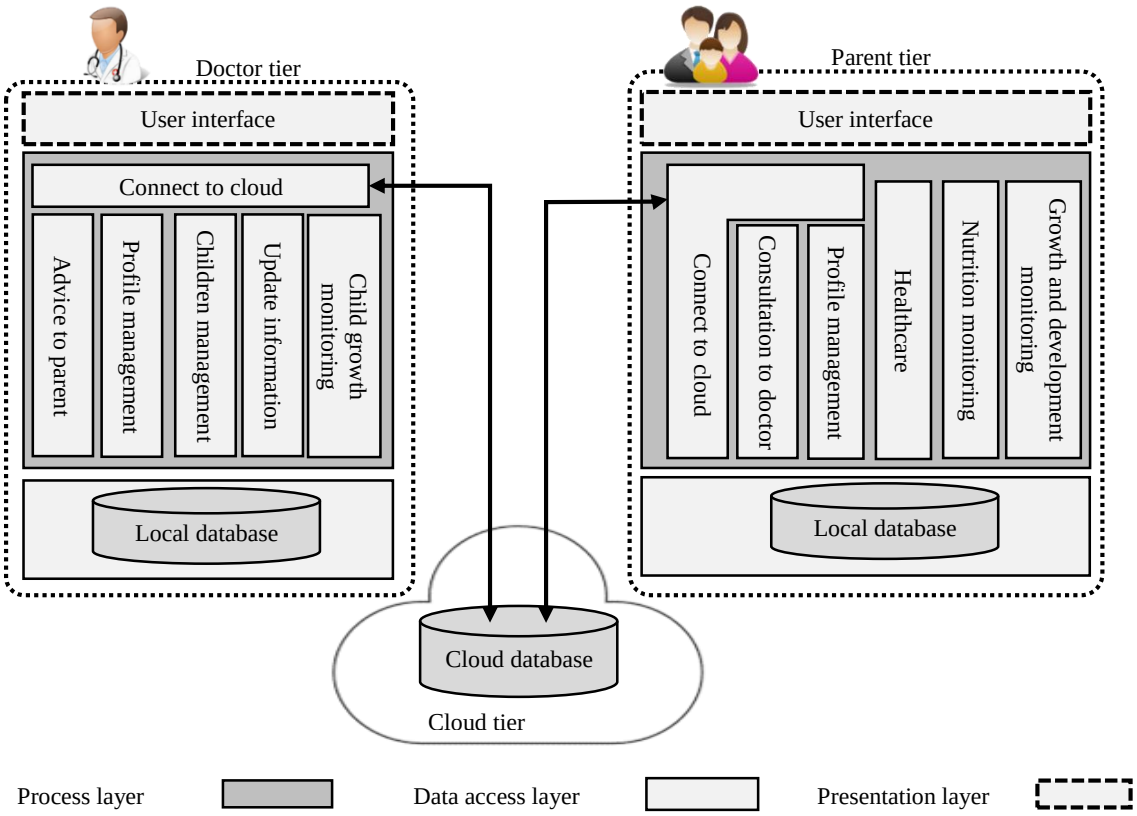

Figure 1. Architecture of the PIG system

Each of the doctor tier or parent tier have their own internal architectures, the designs of which are based on the layered pattern. The layered pattern enables the system to be divided into separate units in a way that each unit can be developed, and maintained independently. This pattern provides the system with portability, modifiability, and reusability[45]. The layered pattern divides a system into some layers, each of which includes a group of components and provides specific services. Each layer is allowed to use the lower-layer services[45]. Each element of the system is described as follows:

4-1. Parent tier

Figure2 shows the architecture of parent tier with the help of the layered pattern. This architecture consists of three layers including presentation, process and data access.

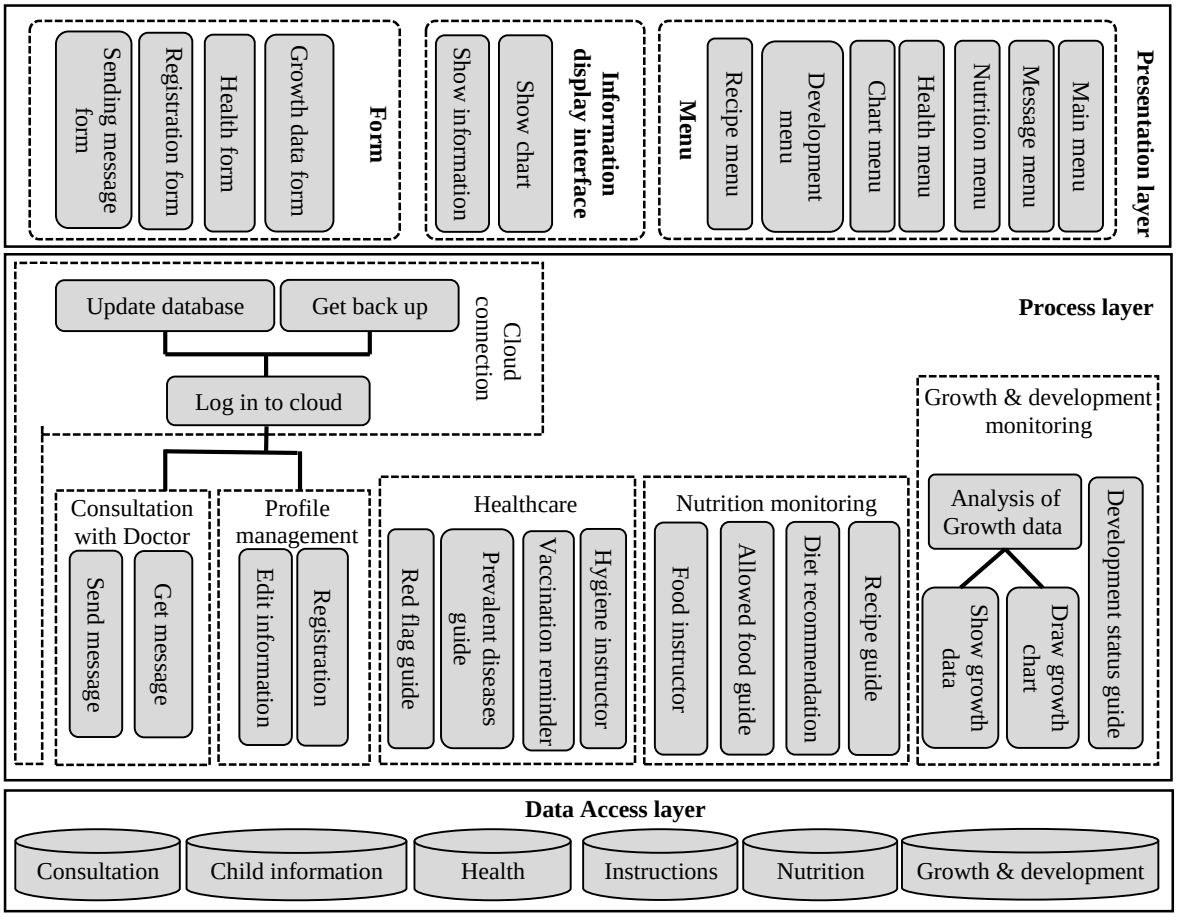

Figure 2. Architecture of the parent tier

The data access layer is the lowest layer containing the databases used by the parental application.

- **Child information database**: It includes the child growth information and related contextual information including weight, height and head circumference data, measurement date, and the result of growth analysis.
- **Growth & development database**: It stores the standard data collected by WHO. This data is used to draw growth charts and analyze growth data. Moreover, Development database includes the skills and abilities that children attain in each age range.
- **Nutrition database**: It includes three classes of information. One class is used to make diet recommendations. Another class is used to create the allowed food guidance. The last class includes recipes (including the name of foods and their recipes).
- **Instruction database**: It contains the health education information including public health, oral and dental care, as well as food instructions including recommendations for bad eating habits, the child's anorexia, the ways of enriching foods, and recommendations for obesity or impotence.

- **Consultation database**: It contains the sent and received messages.
- **Health database**: It contains the name of vaccine, age of vaccination, the names of prevalent diseases, home remedies, and finally risk symptoms and red flags which require immediate visit of the doctor.

In the process layer, the main system operations are done. This layer executes the main functions to respond to users. It includes the following components:

- **Profile Management**: This component has two sub-components: "registration" and "edit information". The "registration" sub-component is used to register the child and edit the personal information. Two types of information are required for system registration: child's information and cloud registration information. The child's information includes name, ID number, date of birth, and gender. The cloud registration information includes username and password.
  The system preprocesses the information after receiving it. If the information is valid, it is stored in the system and the cloud. Moreover, if the information needs to be changed, the parents can edit it through the "edit information" sub-component. It should be mentioned that the system should connect to the cloud to access this component.
- **Growth & Development Monitoring**: It has four sub-components. The sub-component of "analysis of growth data" analyzes the growth information based on the standard issued by WHO, and stores it in the child information database. WHO provides different standards for monitoring the child growth. Four of these standards provide more comprehensive information for growth evaluation including weight for age, length/height for age, weight for length/height, and head circumference for age[3, 21]. The growth standards are defined according to Z-score[21] with seven values: -3z-score ،-2z-score ،-1z-score ،z-score ،+1z-score،+2z-score and +3z-score; where z-score shows the normal growth[21]. To analyze the child's growth, the child's current status is firstly determined with respect to the position among z-scores. Then the history of the child's growth is investigated. If the child has less growth than the standard, then the growth is inappropriate. Figure3 shows the appropriate and inappropriate growth cases.

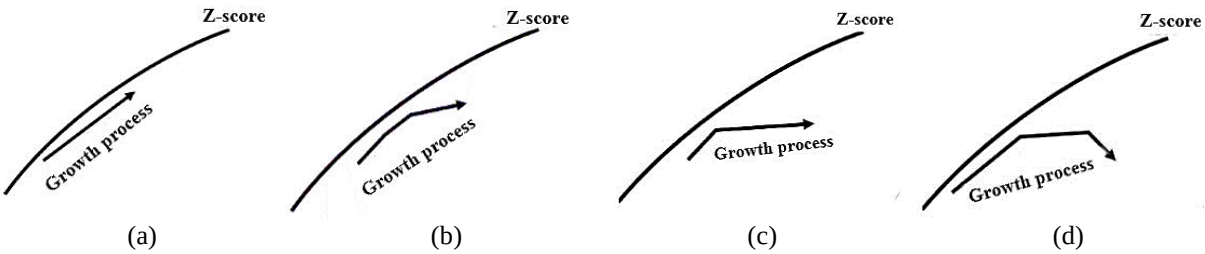

Figure 3. Appropriate and inappropriate status in growth chart
(a) Appropriate growth status: growth process is parallel with the z-score line (b) Inappropriate growth status: the growth is ascending but is not parallel with the z-score line (c) Inappropriate growth status: the lack of growth (d) Inappropriate growth status: growth is descending

In Figure3, the z-score line shows the normal values on the growth chart, and the arrow indicates the child's growth process. Figure3-a shows the appropriate growth status because the growth process is parallel with the z-score line. Figure3-b shows one of the inappropriate growth statuses in which the growth is ascending; however, it is not parallel with the z-score line, and the child is not growing sufficiently. Figure3-c shows the lack of child's growth. The growth (arrow) has been constant for a specific period of time and does not increase. Figure3-d indicates a status in which the child has negative growth. In other words, the child has not grown up at all and suffers from weight loss. Figure4 shows the steps of child's growth analysis.

Figure 4. Process of analysis of the child's growth

The "draw growth chart" subcomponent displays the child's growth diagram by using the recorded contextual information. Also, the "show growth data" subcomponent presents the recorded growth

contexts and enables users to edit them. The "development status guide" subcomponent specifies what activities the child should do in each age range. Generally, the growth & development monitoring component uses "child information" and "growth & development" databases.

- **Nutrition Monitoring**: It contains four sub-components. The context-aware "allowed food guide" sub-component is responsible for determining the age-appropriate foods for children. For instance, the use of complementary foods begins in the first week of the seventh month, and the child is allowed to have milk, rice flour, rice, and sugar. It also specifies sources of nutrients (such as vitamins, protein, minerals, etc.) and the necessary amount of them for a child in each age range. The context-aware "diet recommendation" subcomponent recommends the appropriate diet by considering the contextual information of child's health status, limitations, and dietary norms. Finally, the diet is displayed according to the child's age and growth status. Figure (5) shows the phases.

Figure 5. The process of diet recommendation.

The "recipe guide" provides the recipes for the parents. The "food- instructor" subcomponent teaches the parents necessary dietary points including the correct ways of preserving foods, common symptoms of food allergies, the ways of dealing with bad eating habits and anorexia, and the ways of enriching foods.

- **Healthcare**: It contains four subcomponents including "vaccination reminder", "prevalent diseases guide", "red flag guide", and "hygiene instructor". In the first subcomponent, the child's age is compared with the vaccination dates. If there is a vaccination date within the age range, the parents are reminded of it. The "prevalent diseases guide" describes common and prevalent disease in childhood. Each disease is specified by the primary symptoms and home remedies. In fact, it provides a complete guide about disease for parents. The "red flag guide" subcomponent, describes symptoms that parents should urgently pay attention to, such as fever with abnormal grunting or pale/mottled/ashen/blue color of skin, lips or tongue. If parents face such symptoms, they should visit a doctor immediately. The "hygiene instructor" subcomponent teaches parents the important health points of children.
- **Consultation with the Doctor**: The system enables parents to consult with the doctor. The parents can leave messages for the doctor who can reply to them. This component has two subcomponents: "Get message" for receiving messages and showing them to parents and "send message" for sending a message to doctor.
- **Cloud Connection**: It performs all operations requiring the connection to the cloud. It contains three subcomponents. The "login to cloud" subcomponent does the operations pertaining to the cloud connection and authentication. The parent tier operates according to the information available in the database. The doctor is allowed to change the data of these databases and save the changes in the cloud. The cloud notifies all parents who are under the doctor's supervision. The "update database" subcomponent is responsible for downloading the new database and replacing it. Finally, the "get backup" subcomponent provides a backup of the child information database and sends it to the cloud.

The presentation layer is responsible for displaying information and receiving data from users. It includes three subcomponents of menu, form and information display interface. This layer provides four forms to receive information from parents including registration, health, and growth data and sending message forms. Some of the forms also do preprocessing operations on data in addition to receiving information from users in order to evaluate the validity of data. The information display interface subcomponent displays the information to parents. It includes show information and show chart subcomponents. The menu component shows the menus used in the application including main, nutrition, health, message, recipe and chart menus.

4-2. Doctor Tier

This tier represents the architecture of the mobile application installed and run on the doctor's smartphone. The layer pattern is used to design the internal architecture of this tier. Figure6 indicates the general architecture, which is comprised of three layers.

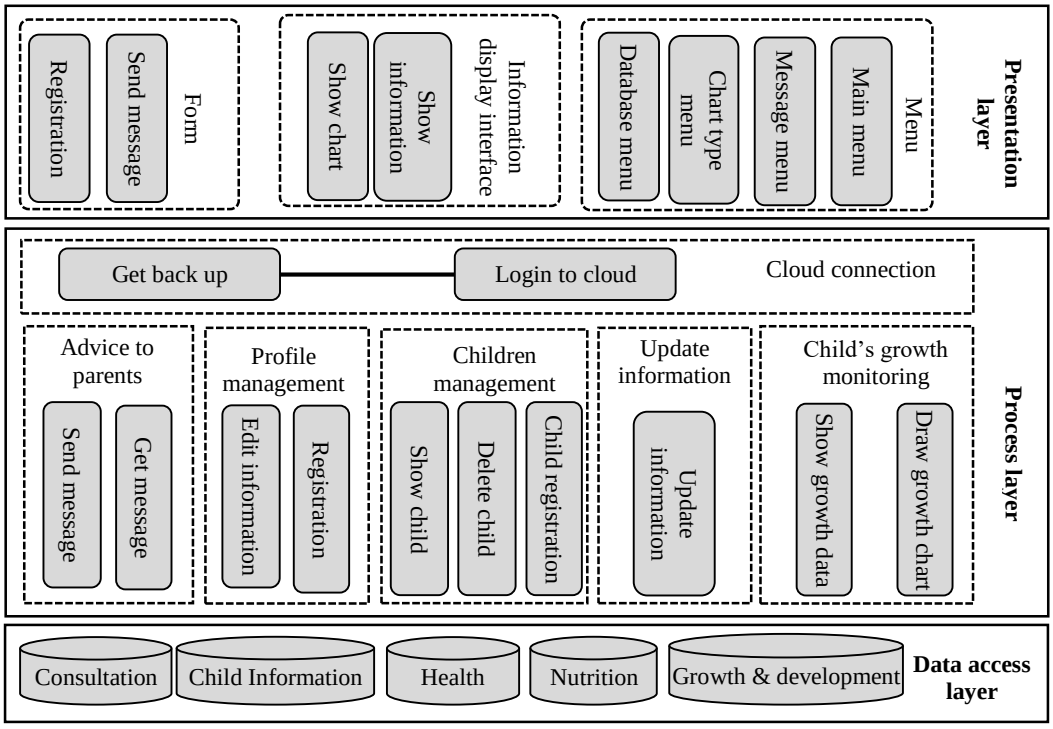

Figure 6. Architecture of the doctor tier

The data access layer is the lowest layer of the architecture in which the necessary data is stored. In the following, the databases of this layer are described:

Child information database: It stores the information of children who are under the doctor's surveillance. The doctor should add a child to the list to monitor the growth process. For this purpose, she uses the child's name and ID number. The child's growth information including height, weight, head circumference, and age are automatically transferred to the cloud and subsequently, to the doctor's device after they have been inserted by the parents. Then the doctor can monitor this information, supervise the child's growth, and see the growth chart.

Other databases include nutrition, growth & development, health and consultation. They are similar to the databases introduced in the parent tier. These databases provide the information required by the parents. The doctor can revise the information of these databases and update them if necessary. Then the updated databases are transferred to the parent tier.

In the process layer, the main system functionalities and operations are done by following components.

- **Profile Management**: It is responsible for registering and editing the doctor's information. It has two subcomponents of "registration" and "edit information". Two classes of information are required for registration. The first class is the doctor's information, including the name and ID number. Registration in the cloud includes the username and password. This information is stored in the system and the cloud.
- **Children management**: It performs the child registration and removal operations in the doctor's tier. It has three subcomponents including child registration, delete, and show. The doctor inserts the supervised children through "child registration" subcomponent, which is connected to the child information database. Also, the doctor can see all her supervised children with "show child" subcomponent, and delete a child through "delete child". When a child is deleted, the relevant information is removed from this database.
- **Child's Growth Monitoring**: The doctor can access the information pertaining to the supervised children and request for a growth chart for each one. This component has two subcomponents: "show growth data" and "draw growth chart". "Show growth data" is used to display a child's growth data and "draw growth chart" is used to draw and display growth chart. This component uses growth & development as well as child information databases.

- **Advice to Parents:** The doctor could communicate with parents and reply to their queries. This component has two subcomponents including "get message" for receiving and showing messages and "send message" for sending a message to a parent or several parents.
- **Update Information**: The doctor could apply the necessary updates to any given database. Then the changes are sent to the cloud and stores. The cloud notifies and updates the parents of the children supervised by the doctor. The databases that can be updated by the doctor include "nutrition", "growth & development", and "health" databases. The presence of newer and richer resources and the adaptability of the system to the local conditions are among the factors, which may result in information update.
- **Cloud connection**: It contains two subcomponents including "login to cloud" and "get back up" on the cloud.

In the same way as the presentation layer in the parent tier, here the presentation layer shows information and receives data from the doctor. This layer has three components including form, menu and information display interface. The form component receives data from the doctor. It has two subcomponents including registration, and send message forms. The information display interface component shows the information to the doctor. It includes show data, and show chart. The menu component shows the menus used in the doctor tier. It includes message, main, chart type and database menus.

4-3. Cloud Tier

The cloud tier stores the doctor and parents' information. The cloud provides a storage and backup space for users. Actually, "data as a service" is used to store parents and doctors information and manage them. Each user should first become a member of the cloud to use its services. The cloud stores each user with the following information:

- Username and password: it is received at the time of registration. They are unique for each user.
- First name and last name: the doctor's name or the child's name is received at the time of registration.
- Category: the cloud users are divided into two groups including parents and doctors. If the parent tier makes a registration request, this value is adjusted to Parent. Similarly, if the doctor's tier issues a registration request, this value is set to Doctor.

Then, the user can use the cloud space to store information, which includes backup files of data. Each stored datum includes ID, name, and an access level, which specifies who is authorized to use and download that data.

5- Experiments

Nowadays, Android has become a popular mobile operating system and the majority of people use android devices. Therefore, the proposed PIG system has been implemented by Android programming language using Android Studio 2.2.1. Moreover, SQLite 2.5.1 has been employed to design its databases. Growth part of Growth & development database has been designed according to the standards issued by WHO[46]. Development part of the "growth & development" database as well as "nutrition", "instruction", and "health" databases have been designed by the reference specialized books of pediatric [3, 22].

Figure7 shows some interfaces of the implemented parent tier. Figure7-a indicates the child's registration form, which receives name, username, password, gender, and birthday of the user. Figure7-b shows the child's growth information form. Figure7-c shows the growth chart. Also Figure7-d shows the prevalent diseases page. Similarly, figure8 shows some interfaces of the implemented doctor tier.

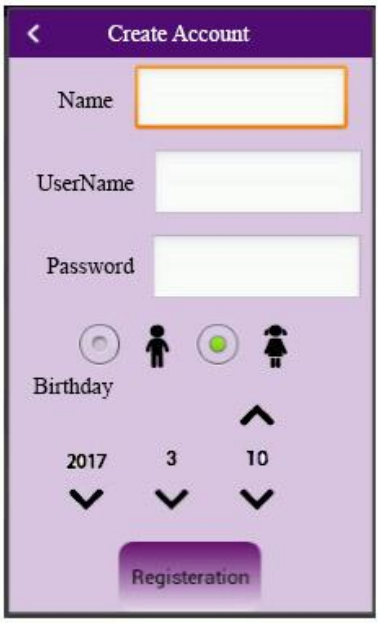

Figure 7-a. Child registration form

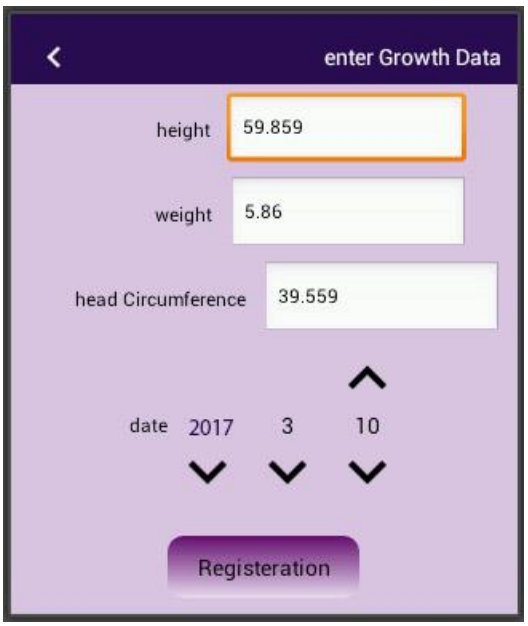

Figure 7-b. Child's growth information

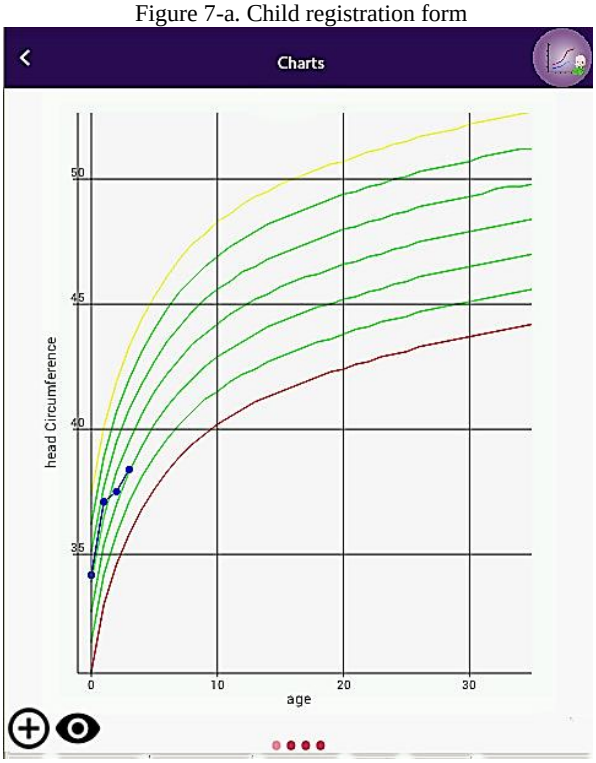

Figure 7-c. Growth chart

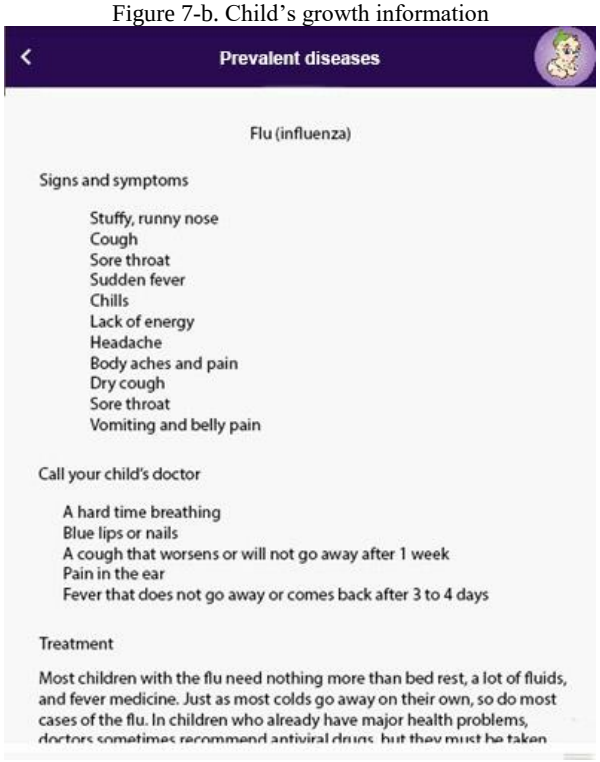

Figure 7-d. Prevalent diseases page

Figure 7. Samples of user interfaces of parent tier

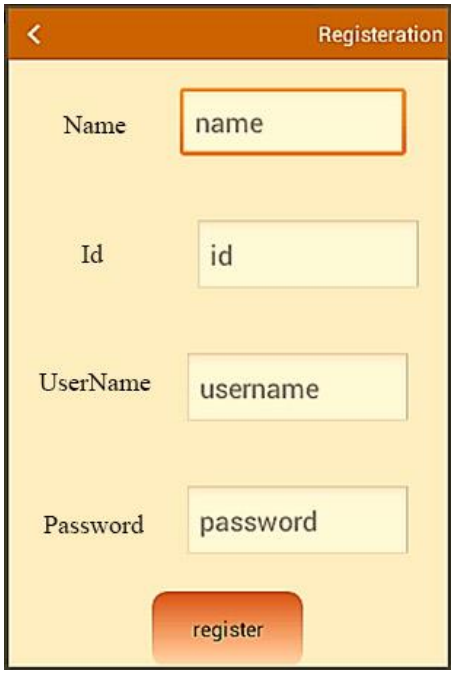

Figure 8-a. Doctor registration form

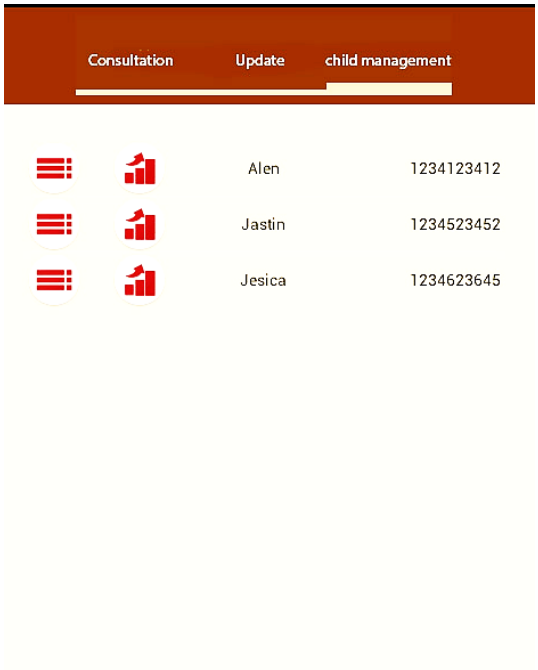

Figure 8-b. Children list

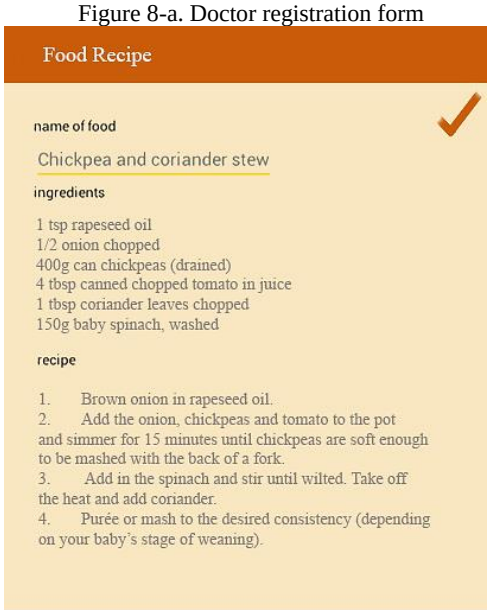

Figure 8-c. Update recipe information from

Figure 8-d. Doctor edits recipe from nutrition database

Figure 8. Samples of user interfaces of doctor tier

The SAAM method is employed to evaluate the architecture of the child's growth monitoring system[47, 48]. It is the most well-known method for evaluating software architectures. The evaluation phases are as follows:

- The first phase is to develop a scenario for each functionality, which has already been dealt with.
- The second phase is to describe the designed architecture, which has been described in the previous section.
- The third phase is to assign weights and priorities to scenarios. In the PIG system, it has been assumed that all of the scenarios have equal priorities.
- The final phase is to evaluate the scenarios. This phase is performed by the sequence diagram. The scenarios are investigated and evaluated here now.

Child growth and nutrition monitoring

This functionality refers to “growth monitoring”, “nutrition monitoring”, “growth monitoring by doctor”, and “consultation with the doctor” sub-functionalities. In the following, the PIG system is investigated according to the related scenarios.

The most important issue that Alice faces is the "nutrition monitoring". She does not have enough knowledge about suitable food and the food preparation process. Another issue is to decide what to feed the baby. She does not know what nutrients to use and how to prepare them, how to preserve the leftovers and what the food allergy symptoms and appropriate foods in diseases are, etc.

Figures9, 10 and 11 show the sequence diagram of the PIG for addressing the “nutrition monitoring” issues. Figure9 shows how the diet recommendation process is performed by the PIG system. To this end, Alice selects nutrition part from the *main* menu and diet part from *nutrition* menu, then specifies the child’s health status of the health form component and sends data to the *diet recommendation* component. Next, this component makes a request to get child’s growth status of *child information* database. Then it requests the diet from *nutrition* database. Finally, the diet is shown to Alice through the *show information* component.

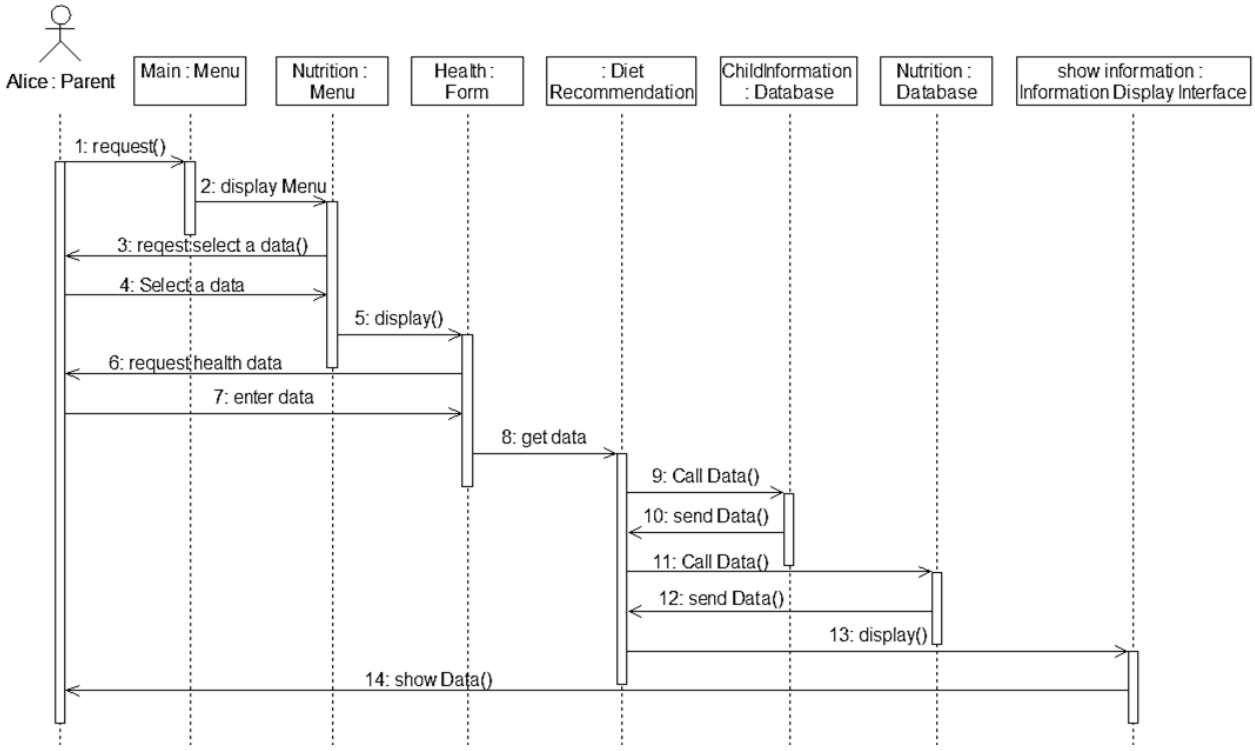

Figure 9. The sequence diagram of the PIG diet recommendation for “nutrition monitoring”

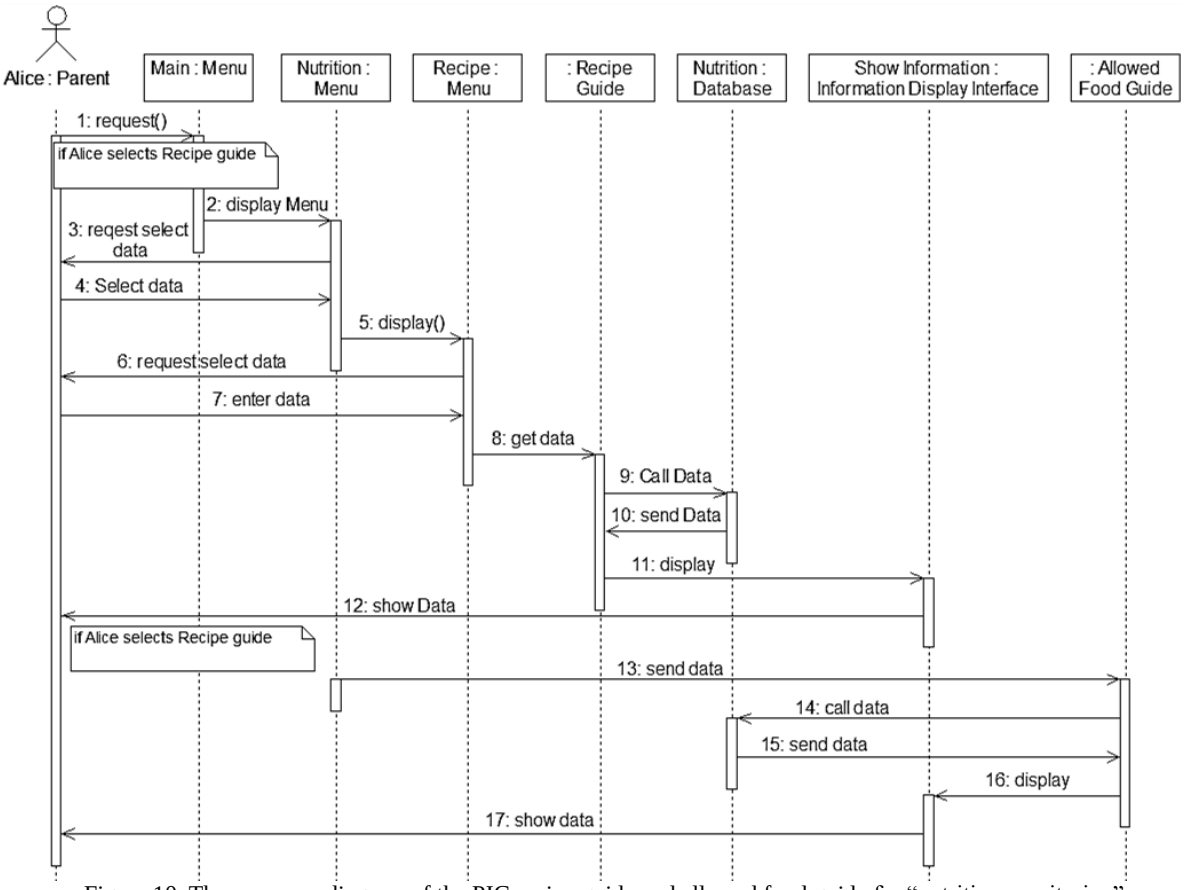

Figure 10. The sequence diagram of the PIG recipe guide and allowed food guide for “nutrition monitoring”

Figure10 shows how the PIG system satisfies the recipe guide and the allowed food guide. Similarly, figure11 shows the execution sequence diagram of the food instructor by the PIG system. Alice requests it through the *nutrition* menu. Then the system gives this request to food instructor. This component receives the information from the *instructor* database and provides Alice with a list of instructions through the *show information* component.

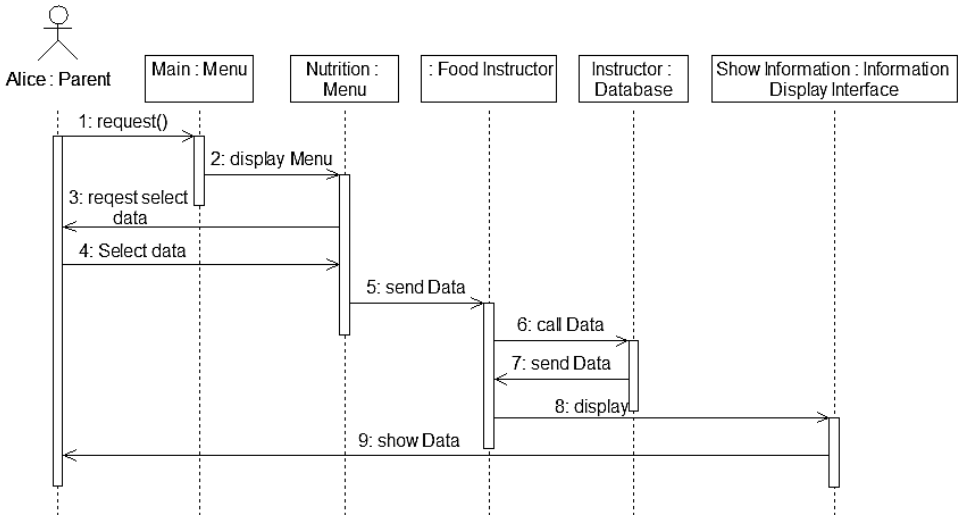

Figure11. The sequence diagram of the PIG food instructor for “nutrition monitoring”

Figure12 shows the sequence diagram of growth monitoring executed by the PIG system. Alice regularly inserts the growth data into the system through the *growth data* form. The system receives them and gives them to the "analysis growth data" component. It receives the standard growth data from g*rowth & development* database. After analysis, the growth data is stored in *child information* database with the results of analysis. Then Alice can

make a request for *draw chart*. She chooses the type of growth chart from the *chart* menu. Finally, the *growth* chart is shown to Alice through the show chart component. Moreover, if Alice chooses one point of the *growth* chart, the relevant information from *the child information* database is shown to her.

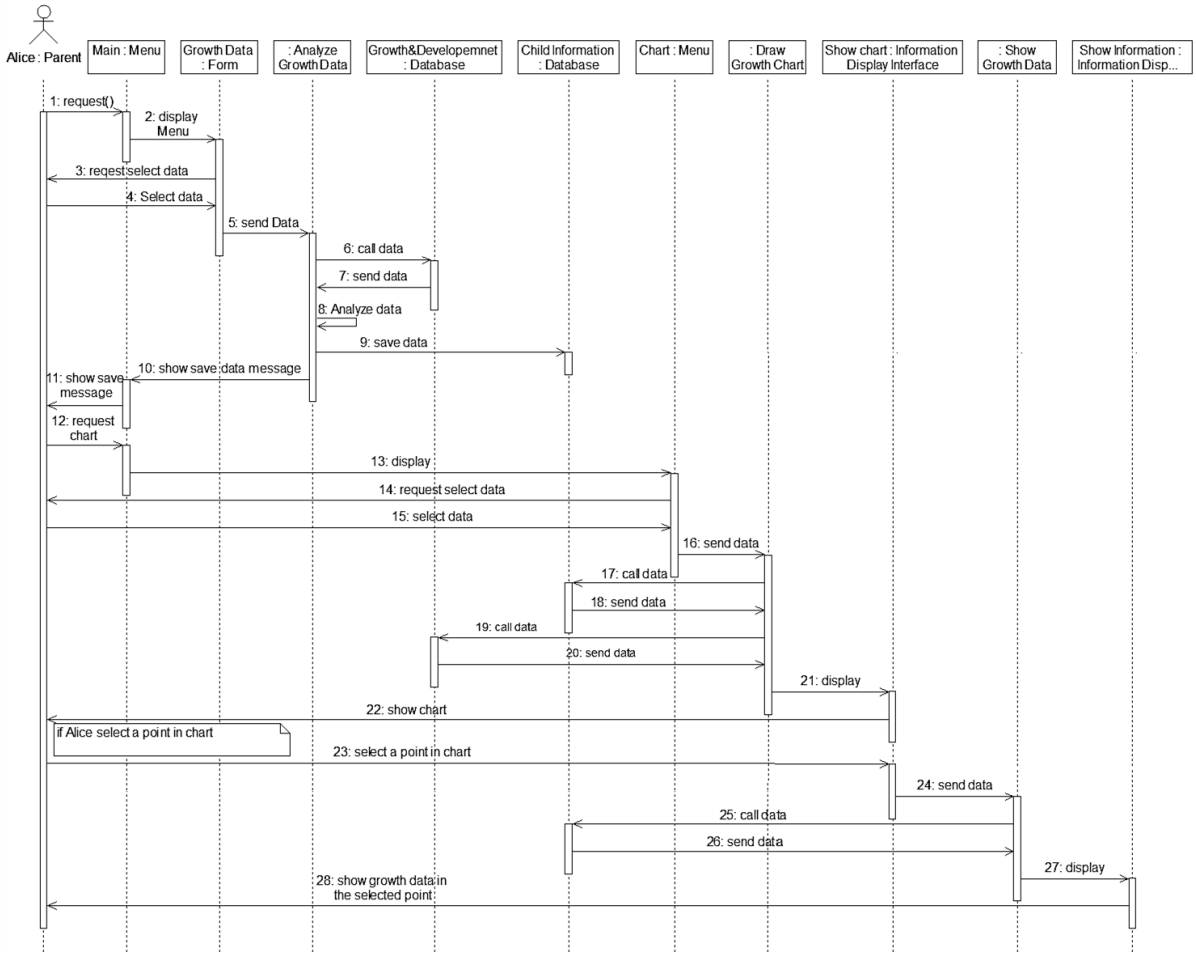

Figure 12. The sequence diagram of the PIG growth monitoring

Besides, figure13 shows execution of the "growth monitoring by the doctor" by the PIG system. To this end, the doctor requests for growth monitoring through the *main* menu. Then system makes a request for a list of the children who are under the doctor's supervision to the cloud. After receiving the information, it displays them. The doctor selects a child as well as the type of the chart. If the doctor selects a point on the child's growth chart, the detail of the information is displayed.

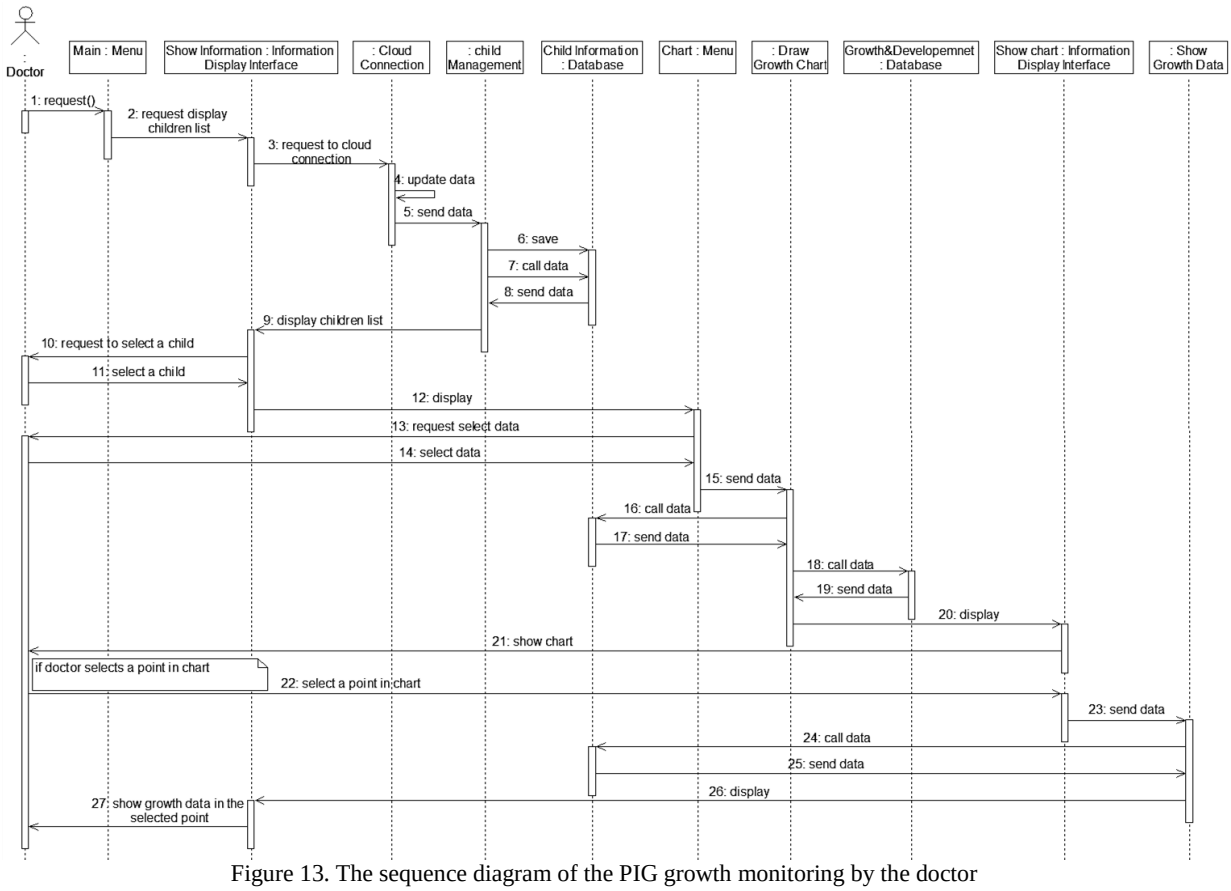

Figure 13. The sequence diagram of the PIG growth monitoring by the doctor

"*Consultation to doctor*" is the next sub-requirement, which is addressed by the proposed PIG system (Figure14). For this, if Alice chooses *send message*, the message form is displayed to her and system makes a request for connection to cloud, simultaneously. After she writes her message, it is stored in the cloud and *consultation* database. Then the delivery message is shown to her. Similarly, on the doctor tier, these steps are run and they can receive messages and answer to them.

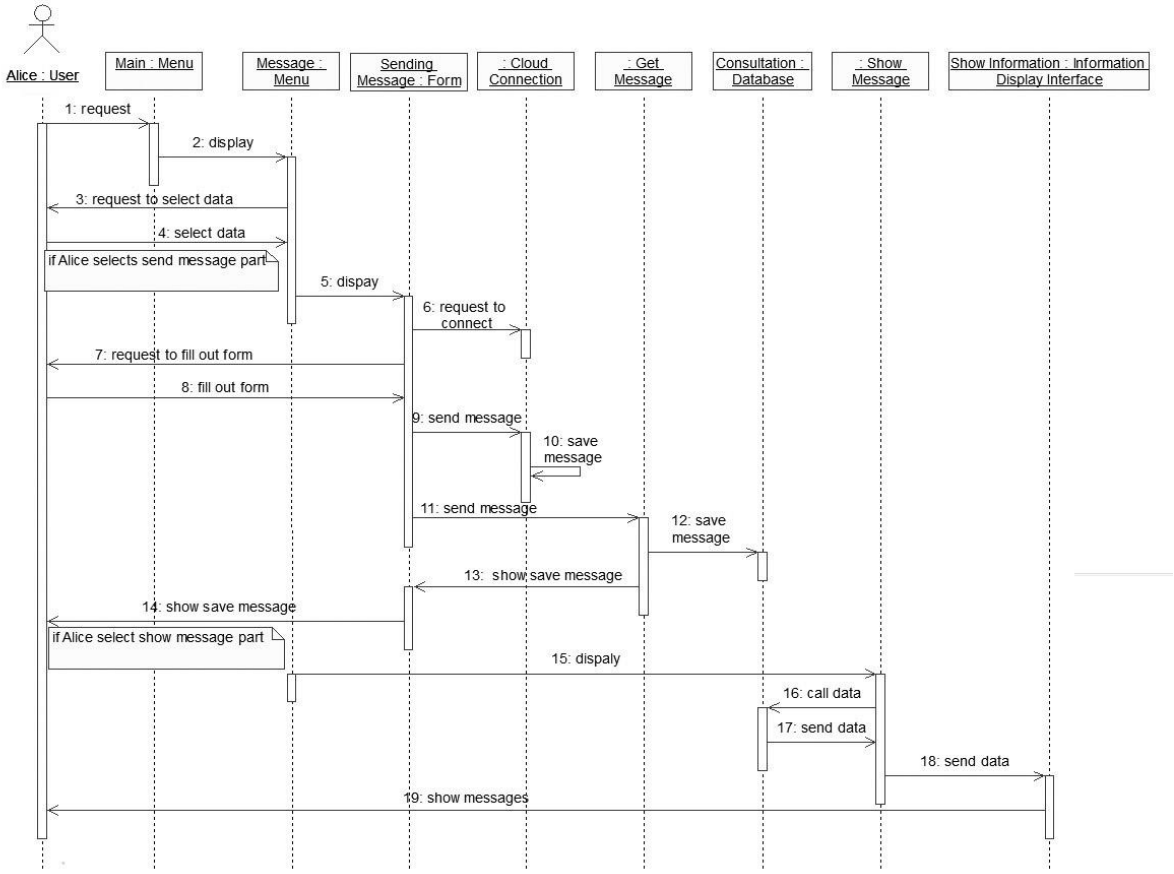

Figure 14. The sequence diagram of the PIG consultation to doctor

Child health monitoring

The second requirement includes the sub-functionalities of prevalent diseases guide, red flag guide, development guide, and vaccination reminder. In the following, the proposed system is investigated regarding these sub-functionalities. Figure15 shows the sequence diagram executed by the PIG system for satisfying the "prevalent diseases guide" and “red flag guide”. Julia can request the display of the *prevalent diseases guide* or the *red flag guide* from the *health* menu. Then the information is shown to her through the *show information* component.

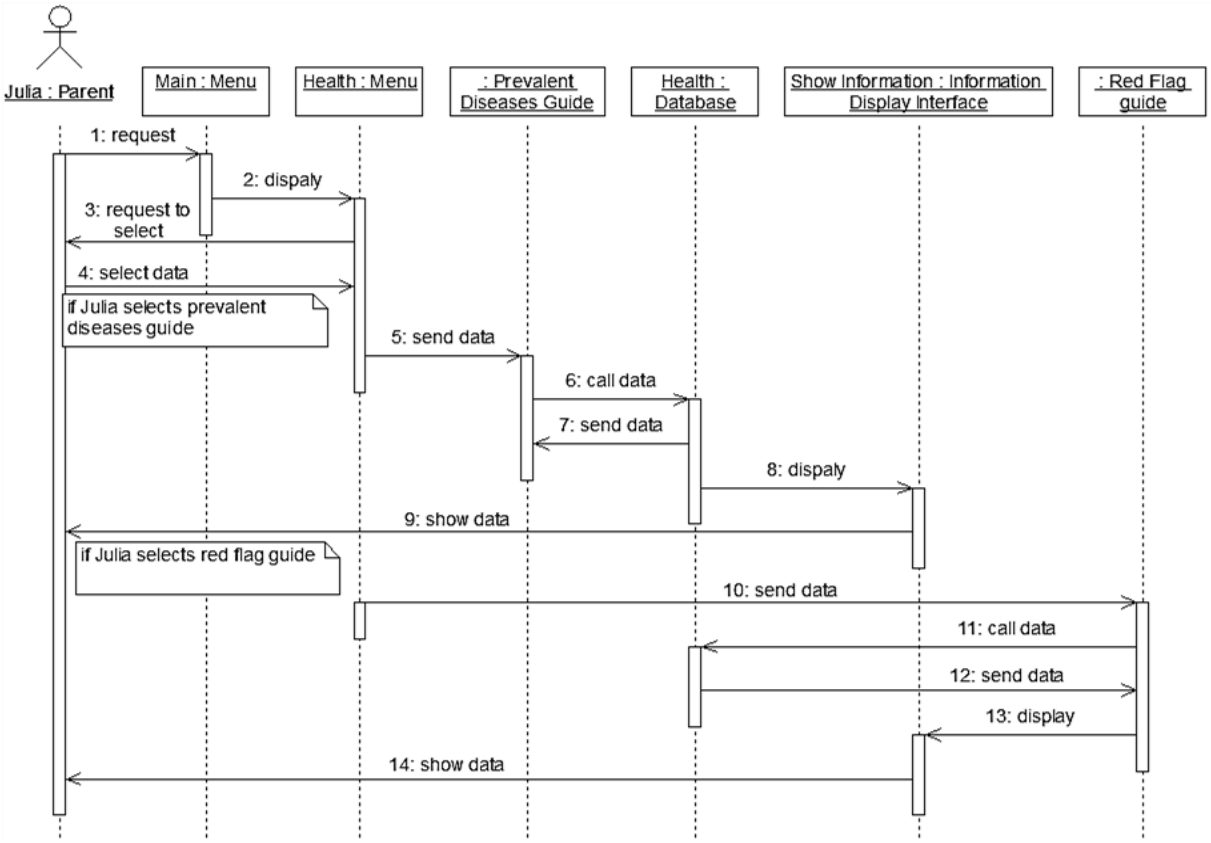

Figure 15. The sequence diagram of the PIG prevalent diseases guide and red flag guide for "health monitoring"

In the child health monitoring scenario, Julia's child has a developmental disorder. The symptoms have been neglected by Julia due to her lack of knowledge about how a child should behave at an age and what skills and capabilities he should have. Figure16, shows the sequence diagram executed by PIG for the development guide. To this end, Julia chooses the development status in the first step. Then she chooses an option (hearing, vision, speech & language, gross motor and fine motor skills, etc.) through the *development* menu. Finally, the information is shown to her through the *show information* component. Therefore, Julia can observe the age-appropriate or age-inappropriate behaviors of her child and detect any abnormalities as quickly as possible.

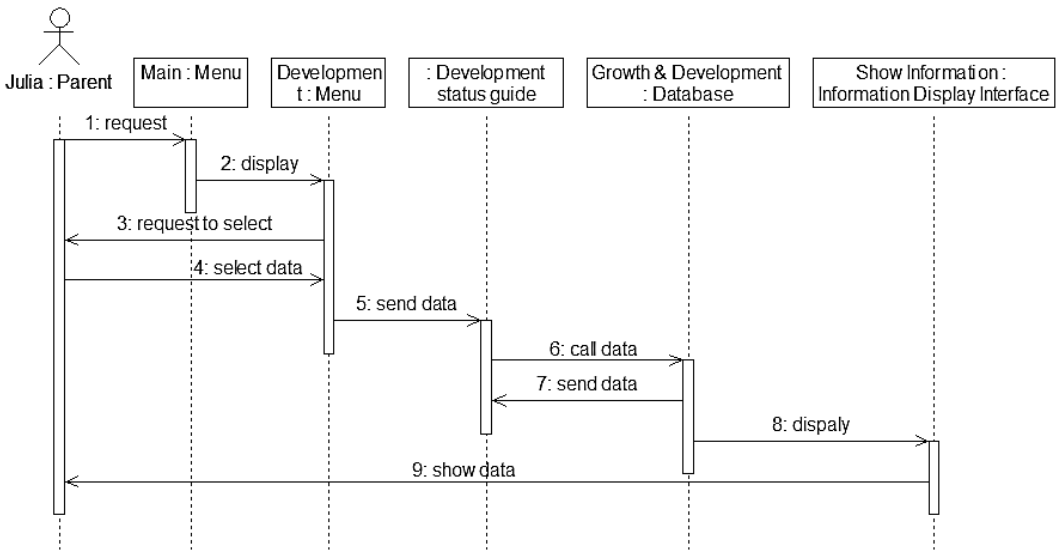

Figure 16. The sequence diagram of the PIG development guide for "health monitoring"

Finally, according to the child health monitoring scenario, Alice has forgotten the vaccination date; therefore, her child's treatment process has become worse. The PIG system could address this issue by the vaccination reminder sub-functionality. Figure17 shows the executed sequence diagram for vaccination reminder. To this end, Alice requests the *vaccination reminder* through *the health* menu. Therefore, when the vaccination date matches the child's age, she is notified.

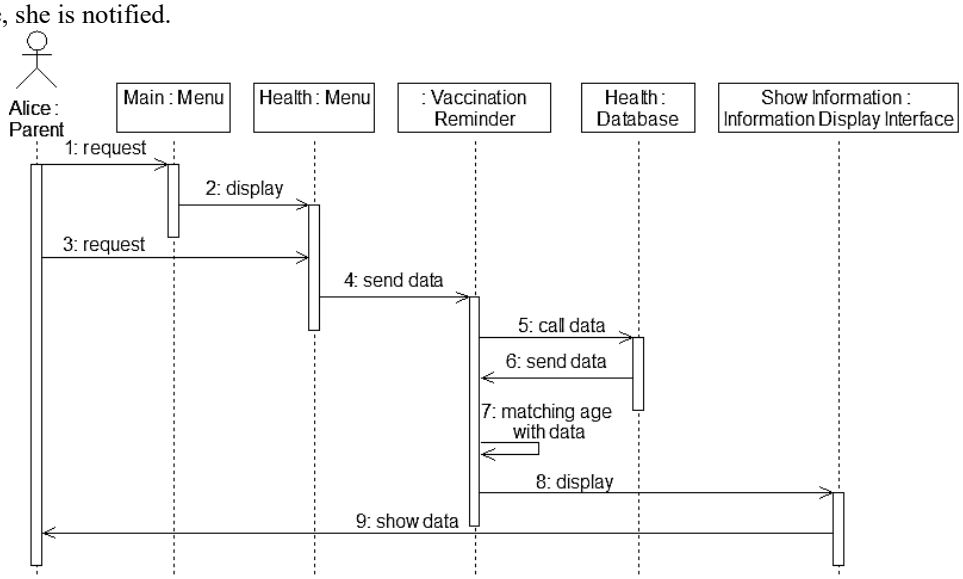

Figure 17. The sequence diagram of the PIG vaccination reminder for "health monitoring"

Doctor intervention

According to the doctor intervention scenario, Dr. James and Dr. Parker's application suffers the problem that data cannot support the patients of both doctors. The proposed system resolves this issue by enabling doctors to update and customize information. Figure18 shows how the PIG system satisfies this scenario. Dr. James first requests to update the database information for his patients. Then the update is applied in the cloud. Moreover, cloud sends a notification to *update information* component in parent tier. This notification is shown to parents through *show information* component. After accepting the notification, the *Update information* component saves data into the parent tier database.

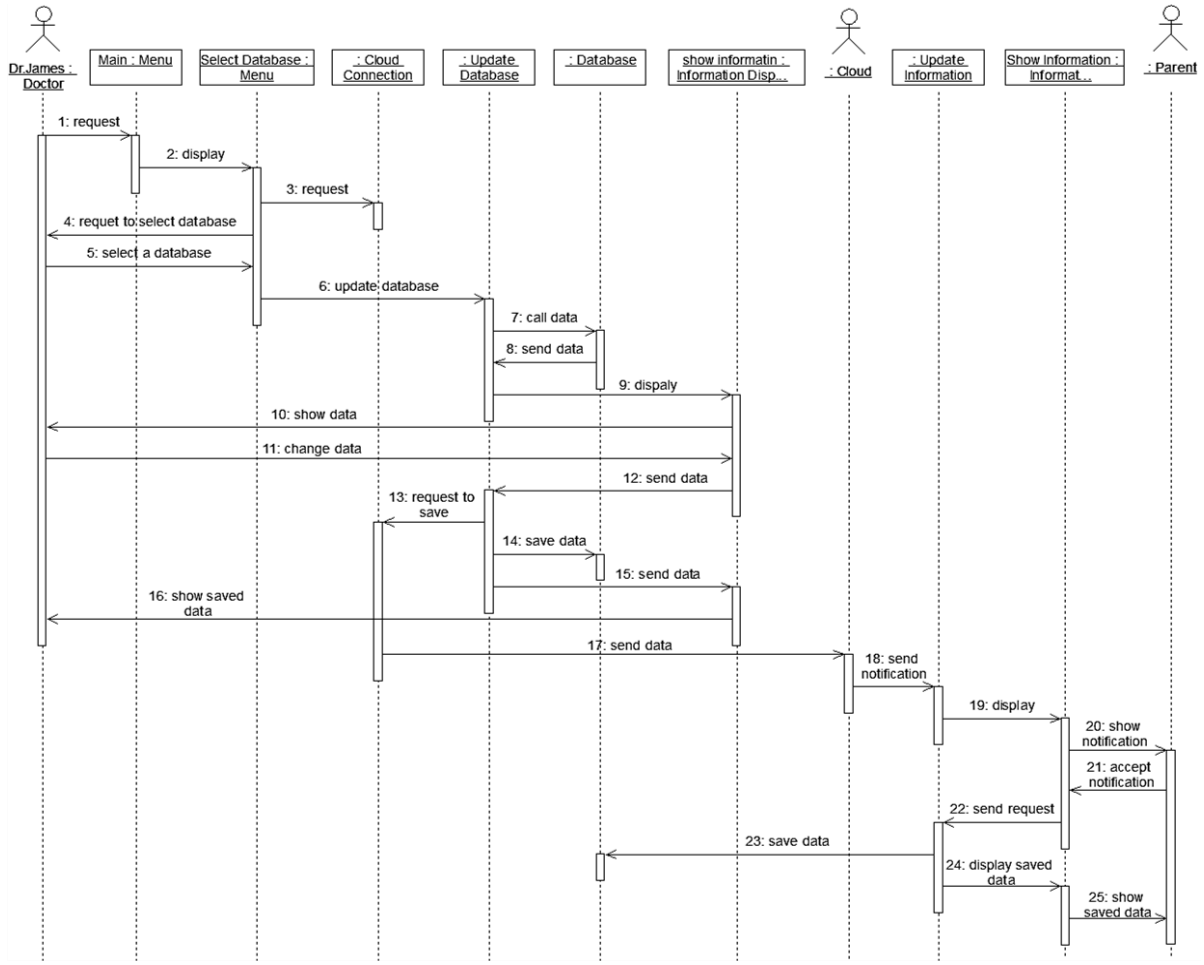

Figure 18. The sequence diagram of the PIG update database

In the final step of SAAM, the proposed system is compared with the similar systems. Table (1) shows this comparison. In this table, the most similar studies and applications are selected with respect to their levels of popularity. All of them are described in the second section. These systems include "child growth mentor"[38], “baby care-tracking growth”[39], “baby complete guide”[40] , “baby care, baby recipes, tracking” [41], and “baby growth chart & complementary foods”[42].

Table 1. Comparing the proposed system with similar systems

System / Functionality and sub-functionality	Proposed PIG system	Child Growth Mentor[38]	Baby care-tracking growth[39]	Baby growth chart & complementary foods[42]	Baby Complete Guide[40]	Baby care, baby recipes, tracking [41]
Growth and nutrition monitoring						
Nutrition monitoring	+	+	-	+	+	+
Growth monitoring	+	+	+	+	+	+
Consultation to doctor	+	-	-	-	+	-
Childs’ Growth monitoring(by doctor)	+	-	-	-	-	-
Health monitoring						
Prevalent diseases guide	+	-	-	-	-	-
Development guide	+	-	+	-	+	-
Vaccination reminder	+	+	+	+	-	-
Doctor intervention						
Update information	+	-	-	-	-	-

In Table (1), rows contain the system functionalities and sub-functionalities. Columns include the related pieces of research. Moreover, + refers to the presence of a functionality or sub-functionality in the system, and – shows its absence.

Regarding growth and nutrition monitoring, the majority of systems show parents the foods and recipes. However, none of the systems enable the doctors to analyze the growth status. They only show parents the child's position on the growth chart. Regarding contacting the doctor and the availability of doctor, among the previous systems only "baby complete guide" can enable the users to contact the doctor or pediatric. In this system, the replies are provided by a group of doctors but they cannot answer the questions specifically because of not having the necessary information on child's health, and growth status.

Regarding healthcare, most of the systems remind parents of vaccination dates. In spite of that a disease can have a great effect on the child's growth and nutrition, none of the previous systems have any special capability regarding the prevalent childhood diseases as well as how to take care of children and provide them with useful nutrition during a disease. It should be noted that, the consumption of some nutrients is forbidden during a disease, and other foods are necessary. In some cases, it is necessary to use some specific diets.

Although, it is possible that the type of nutrition and even diseases may be different in different areas, none of the previous systems support customization of data by the doctors.

Generally, the proposed system is more comprehensive than other systems in the child's healthcare area. In addition to drawing the child's growth chart for the parents, the PIG system can analyze the child's growth status and use the results to make recommendations on diets. Moreover, it considers the child's health status to recommend diets. It also makes the parents acquainted with the prevalent symptoms and diseases of children as well as home remedies and treatment methods. It also enables doctors and parents to interact with each other. In other words, parents can ask the doctor about their questions and challenges. On the other hand, due to the doctor's supervision on the child's growth procedure and the availability of doctor to answer the questions, the proposed system can be more reliable for parents. Since the data of parental application can be changed by the doctor tier, this system can be easily localized, and the doctor can change the information used by parents with respect to the patient's conditions and the state of the art of the science.

5- Conclusion

In this research, pervasive system for infant's growth and nutrition monitoring has been proposed to help parents improve the childcare process. This system consists of two mobile tiers and applications including the parental and the doctor's side. It has the growth and nutrition monitoring, health monitoring and doctor intervention functionalities. The parental side tier is a context-aware system, which uses contextual information such as age, health status, and growth status to guide parents regarding the child situation. It enables parents to monitor child's growth, nutrition, and health status as well as contacting the doctor. The doctor's tier enables the doctor to monitor the child's growth status, update the information, and contact the parents. The multi-tier pattern has been used to design the system, which has been divided into three tiers including the doctor, parents and the cloud. The doctor and parent tiers have been designed according to the layer pattern. Each of them has three layers including the presentation layer to interact with the user, the process layer to do the system operations, and the data access layer, which includes the databases. Given the limitations of smartphones, the cloud has been used as a platform to manage, store and backup the data.

The system architecture has been evaluated through the SAAM. To this end, scenarios have been defined under a pediatrician's supervision for each functionality. Then the execution procedure of these scenarios have been investigated by the sequence diagram. Finally, the proposed system has been compared with other similar systems. The results have shown that this system is more comprehensive that other available systems in this area. Particularly, since the system is able to analyze the growth chart, it can help parents determine the child's growth status. The doctor is also able to receive data and monitor the growth of children. The proposed system is able to make recommendations on diets based on the child's growth status, health and age. In addition, it makes parents aware of risk symptoms and prevalent diseases. The doctor can also localize, update and modify the data used by the parental system according to the latest references. These changes are only applied to the system of parents whose children are under the same doctor's supervision.

The proposed system targets only healthy children, whereas there are many children with special problems and diseases. There are also some children born prematurely. Since these children need more attention and care, mobile health should be used for them, too. In addition, nowadays ICT developments result in the advent of different

medical sensors that can be integrated with mobile devices. These sensors can be used to follow the child's health status much better and improve mobile health services for children.

Compliance with Ethical Standards

Authors declare that they have no conflict of interest.
Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

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