Empowering the Citizen in the Main Pillars of Health by Using IoT

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Abstract. To live longer, healthier, and more active, people at any age have to follow simple and clear suggestions that cover the 3 main pillars of health: physical activity, nutrition, and sleeping. Unfortunately, due to the intrinsic (e.g., daily-life habits) and extrinsic (e.g., environmental change) factors, people are far to have a healthy life and, thus, there is an increase of chronic diseases, mental disorders, and premature death. Approaches to increase citizen empowerment vary from self-management programs to those for promoting citizen (especially patients) involvement in treatment shared decision-making, to those to facilitating also the clinician-patient cooperation, when required. This paper presents the approach followed in CarpeDiem, an IoT-based system focused on self-management as a way to engage and empower citizens in order to improve their quality of life, to allow a better follow-up by clinicians in case of patients or elderly people, and to improve training in case of sportsmen.

Keywords: Healthy habits · Citizen empowerment · Physical activity · Nutrition · Sleeping activity · Activity monitoring · Recommender system

1 Introduction

Digital tools represent a valuable potential resource for healthcare systems, especially when addressing populations with a high prevalence of risk factor clustering. However, although technological innovations may provide monitoring instruments which can improve person-centred care, they are often ineffective or underutilised due to barriers associated with implementation. These include issues such as the incompatibility of the technology to the local context, limited interoperability, poor system performance, increased cost, lack of financial incentives, inadequacy of legislation and policies, poor organisation of work, health

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professionals' resistance, lack of leadership, negative attitudes and beliefs, lack of planning [25].

In this scenario and according to the P4 medicine paradigm [19], we claim that facilitating new forms of active participation by patients, citizens, and consumers in the self-management of personal health data will allow disease prevention for healthy citizens [10,28].

There is not a universally accepted definition of self-management [4]. Alderson et al. refers to it as "an inter-disciplinary group education, based on the principles of adult learning, individualized treatment and case management theory" [2]. On the other hand, in [22], authors define self-management as a treatment that combines biological, psychological, and social intervention techniques, with a goal of maximal functioning of regulatory processes. In contrast, in [10], authors interpret self-management as the "day-to-day tasks an individual must undertake to control or reduce the impact of disease on physical status.". Accordingly, four kinds of self-management approaches have been identified, depending on the role of the healthy citizen or the patient [5]: subordinate, structured, collaborative, and autonomous. Subordinate tools are those that provide modest patient discretion through controlling and supervisory technology. Structured tools require more active, though still limited, patient participation. Collaborative ones involve patient drawing on their own knowledge and making decisions jointly with clinicians. Finally, autonomous tools support patients take matters in hand without much participation from clinicians.

In this paper, we present the CarpeDiem IoT-based self-management system aimed at providing intelligent and automatic support to people who want to maintain a healthy lifestyle. CarpeDiem target users are people who need to follow a strict diet, athletes who want to control their weight and stay healthy, or simply, citizens who want to follow a healthy diet (in a comprehensive way, taking into account nutrition, physical activity, and sleep).

The CarpeDiem self-management system is intelligent and autonomous, and it is aimed at monitoring physical- and sleeping-activity, nutrition, as well as environmental data and lifestyle habits, with the final goal of providing personalized recommendations and nudges to foster behaviour change towards healthier behaviours. The self-management system is composed of a micro-services-based back-end [29], in which intelligent techniques have been implemented for personalization and automatic monitoring, and a front-end in form of an app to be installed in the citizen's smartphone. The first prototype of the system is available for Android and 14 healthy users are currently testing it.

The rest of the paper is organized as follow. Section 2 illustrates the overall solution for monitoring activities, environmental data, and lifestyle habits. In Sect. 3, we present the current prototype available in the Android market place. Section 4 summarizes similar works currently available pointing out limitations and differences with CarpeDiem. Finally, Sect. 5 ends the paper with conclusions and future directions.

2 The IoT Self-management System

With the aim of improving healthy habits in the population, we propose an automatic and intelligent system that empowers and supports the citizens giving them personalized recommendations and nudges.

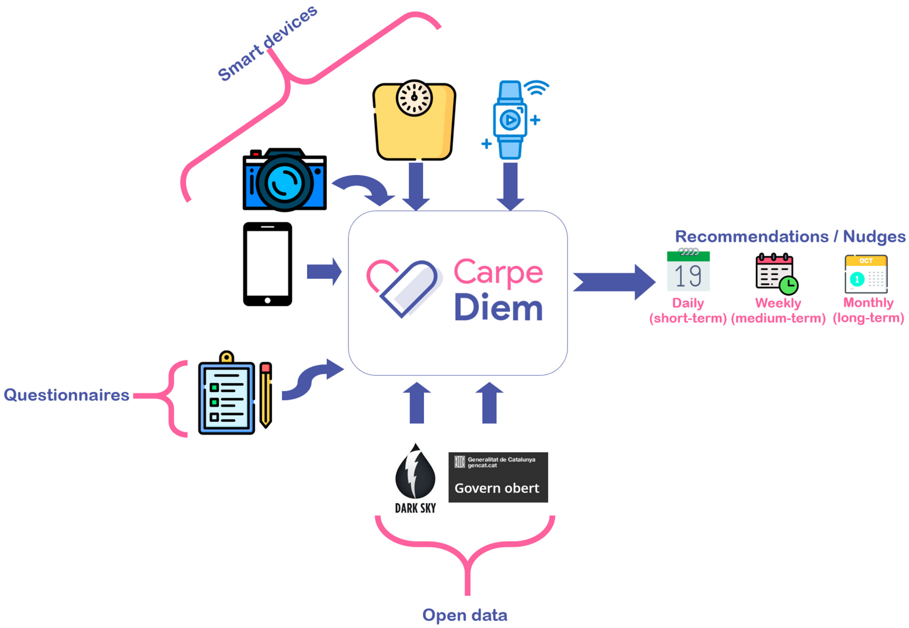

Fig. 1. The CarpeDiem IoT system at a glance.

Figure 1 shows the CarpeDiem IoT-based self-management system that put together data from smart devices (i.e., an activity tracker, a scale, and a smartphone), questionnaires, and open sources (i.e., Dark Sky API[1] and Dades Obertes (open data) from Generalitat de Catalunya[2]).

2.1 Data Collection

As depicted in Fig. 1, the IoT-based self-management system works with a set of data coming from different sources.

CarpeDiem users wear an off-the-shelf activity tracker 24/7. Physical- and sleep-activity are monitored in terms of: number of steps, total number of minutes of activity per level (i.e., low, medium, high, and sedentary), total number of sleeping hours, number of sleeping hours during the night, number of sleeping

[1] https://darksky.net/dev.
[2] http://governobert.gencat.cat/en/dades_obertes/.

hours during the day, number of naps, onset time, offset time, minutes awake, and sleep efficiency. Moreover, the energy expenditure in terms of calories is constantly monitored. Smart scales measure the weight and calculate the body fat scale and uploads the measurements to the cloud by using the WiFi connection [21]. CarpeDiem users are asked to monitor her/his weight once a week in order to take under control her/his Body Mass Index (BMI) and to avoid reaching overweight and, thus, obesity.

The CarpeDiem system integrates the LogMeal API [7], capable of recognizing meals through pictures taken from the smartphone camera. LogMeal is an intelligent cloud-based application which automatically recognizes several dishes, based on images acquired by the user with a smartphone to objectively and seamlessly collect food intake information. The pictures taken by using the CarpeDiem system are automatically sent to LogMeal that analyzes them and gives as output a list of meals. The citizen selects the right one and CarpeDiem automatically indicates the corresponding food group and calculates the number of calories and key nutrients of a dish portion, basing such calculation on the recipes also available through LogMeal.

In the literature, several questionnaires have been identified and are currently applied to monitor the status of citizens (both healthy people and patients) in terms of, for instance, overall satisfaction, anxiety and depression, quality of life, perceived pain, self-care, as well as mental disorder [15]. In CarpeDiem, questionnaires are used to directly ask the users regarding some lifestyle habits. They have to be filled the first time the user enters to the system and, then, once a week or everyday, depending on the questionnaire. To be aware regarding seasonality, daylight hours, and further environmental data, we rely to the Dark Sky API[3]. It allows to look up the weather anywhere on the globe, returning (where available): weather conditions, minute-by-minute forecasts out to one hour, hour-by-hour and day-by-day forecasts out to seven days, hour-by-hour and day-by-day observations going back decades, weather alerts, and humidity.

Finally, to monitor the air quality in Catalonia, the Dades Obertes by Generalitat de Catalunya is used[4].

2.2 The Recommender Systems

The CarpeDiem IoT-based self-management system collects and fuses the heterogeneous data coming from all the data sources and sends personalised nudges and recommendations to empower citizens in better follow-up healthy habits concerning the main pillars of health, according to their profile. Recommendations and nudges are sent on a daily (short-term), weekly (medium-term), and monthly (long-term) basis.

A specific recommender system for each of the pillars has been defined and developed.

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[3] https://darksky.net/dev.

[4] http://governobert.gencat.cat/en/dades_obertes/.

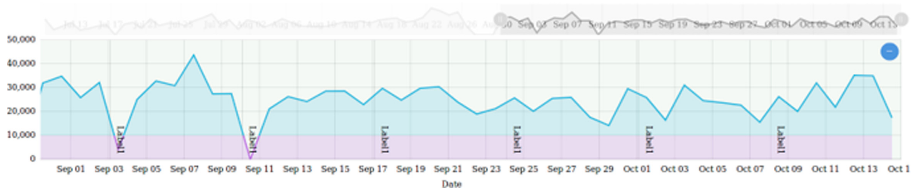

Fig. 2. Example of a volunteer that overpasses her goal every day.

Physical Activity. The Physical Activity recommender system of CarpeDiem improves and extends the one proposed in [17].

Its main functionalities are:

- Computation of the daily adherence of the patient;
- Computation of the adherence profile of the patient;
- Computation of activities during the week;
- Computation of improvements during the month.

Daily adherence is calculated as a percentage of the amount of activity fulfilled against the goal in terms of number of steps. The adherence computation takes also into consideration, for each user, her/his "best" and "worse" days of the week and also National holidays. In doing so, different messages will be sent those days, accordingly. Thanks to the integration of the Dark Sky API, we also consider the weather in order to not push the users to walk if it is snowing or during a storm.

The adherence profile considers prolonged time periods, so as to assess how adherence fluctuates during time. The recommender system relies on two counters, one for the number of consecutive days in which the patients achieved the goal (winstreak), and one for the number of consecutive days in which the patients did not achieve the goal (losestreak). Any time the patient moves from achieving to not achieving the goal, the winstreak counter is reset to 0. The same with losestreak when moving from not achieving to achieving. Early in the morning, the recommender system checks if the day before the goal has been achieved or not, and it updates the counters, accordingly. Depending on the number of days that the patient is achieving/not achieving the goal, the message will be more or less effective. The more the number of days s/he is not achieving, the stronger the message to push the patient to improve. The more the number of days s/he is achieving, the stronger the message to compliment the patient and to push her/him to doing better and better.

Activities during the week are calculated considering the adherence weekly seasonality. The weekdays with less adherence over time are stored. Depending on the day the patient is achieving/not achieving the goal, the message will be different. We do not push the users to walk during the days of the week where the adherence is usually lower, which may be due to impossibility of the user to perform physical activity at certain moments of the week.

Improving during the month are calculated to check if the current goal is still applicable or a new one has to be suggested. For instance, Fig. 2 shows the case of a volunteer that overpassed her goal during all the period. In this case, the recommender system will suggest to increase the goal.

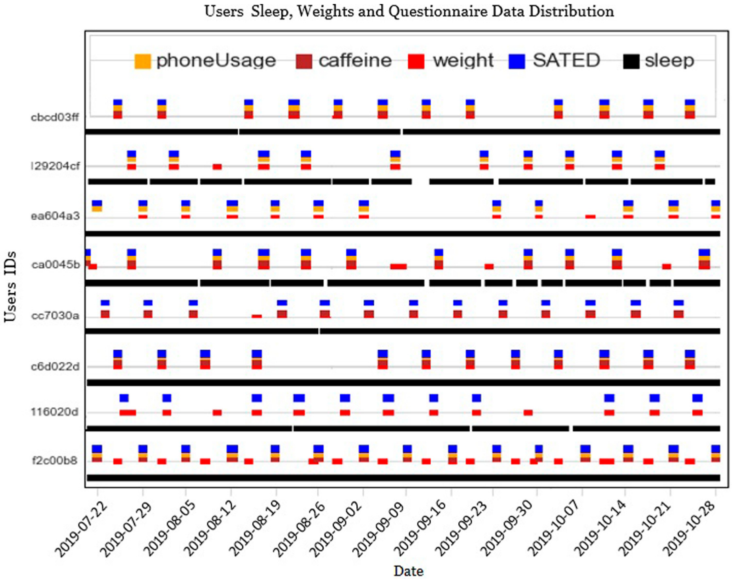

Fig. 3. Data distribution of the 8 selected users collected during the pilot.

Sleeping. In order to define the Sleeping recommender system, data from a 8-months pilot performed during 2019 have been used to create the models [30]. A total of 30 volunteers have been recruited in Barcelona and Lleida (Spain). Volunteers were asked to wear their activity tracker 24/7, to weight once a week, and to answer selected questionnaires at the end of the week. The day of the inclusion, we also took note of the comfort of the bed of each volunteer, as well as her/his address to take into consideration the environmental factors. Due to technical problems and adherence issues, 6 of the 30 volunteers dropped-out before finishing the first month of the study. Thus, the analysis of the data have been done using the data of 24 volunteers (38.43 ± 11.46 years old; 15 females; and 23.09 ± 3.66 BMI). The pilot started on May 2019 and finished in December 2019.

A static profile is first created considering gender and age together with data coming from the questionnaires. That profile will be dynamically and continuously updated by considering the data gathered from the wristband, the changes in the BMI, if any, the questionnaire answers, and the environmental data.

Once the profile is built, the citizen is automatically clustered according to fixed groups of habits defined considering the intersections among the three

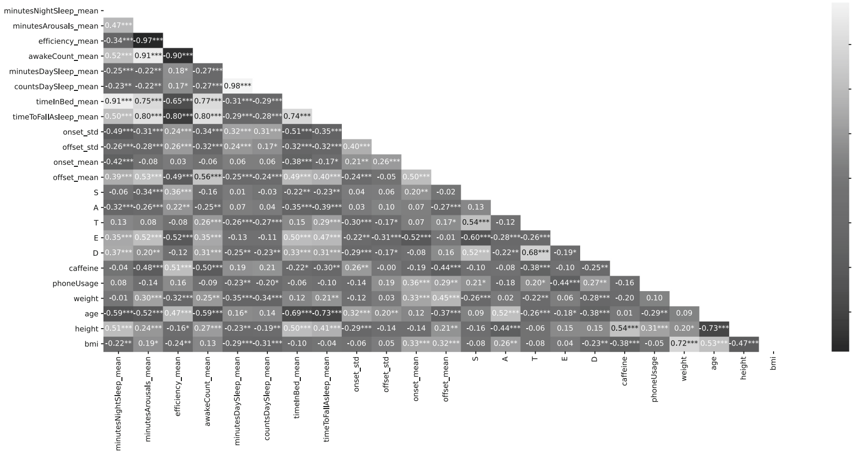

Fig. 4. The correlation matrix between the sleep features collected by using the activity tracker and the questionnaires. The Pearson correlation coefficient is displayed for each parameter pair. Legend of parameter names: *minutesNightSleep_mean* - weekly average of the minutes spent sleeping during the night, *minutesArousals_mean* - weekly average of the minutes spent awake during the night, *efficiency_mean* - weekly average of the sleep efficiency, *awakeCount_mean* - weekly average of the number of awakening times during the night sleep, *minutesDaySleep_mean* - weekly average of the minutes spent sleeping during the day, *countsDaySleep_mean* - weekly average of the number of the sleep periods during the day, *timeInBed_mean* - weekly average of the total time spent in bed, *timeToFallAsleep_mean* - weekly average of the time it takes to fall asleep, *onset_std* - weekly variation of the onset time, *offset_std* - weekly variation of the offset time, *onset_mean* - weekly average of the onset time, *offset_mean* - weekly average of the offset time, *S* - weekly satisfaction answer from SATED questionnaire, *A* - weekly alertness answer from SATED questionnaire, *T* - weekly timing answer from SATED questionnaire, *E* - weekly efficiency answer from the SATED questionnaire, *D* - weekly duration answer from the SATED questionnaire, *caffeine* - weekly averaged caffeine consumption, *phoneUsage* - weekly electronic device minutes of usage before bedtime, *weight* - citizen weight, *age* - citizen age, *bmi* - citizen body mass index. The (*) symbol indicates the significance level: *** if p-value ≤ 0.01, ** if p-value ≤ 0.05 and * if p-value ≤ 0.1.

categories: number of sleeping hours (less than the recommended hours, the recommended hours, more than the recommended hours), sleep efficiency (below or above 85%), and satisfaction with the sleep. The recommended hours are defined taking into account the citizen age, according to what defined in the literature [18]. Similarly, the efficiency threshold is defined according to the work in [23]. Finally, satisfaction is assessed by using the 5 levels of the SATED questionnaire [6]: 1 = Never, 2 = Rarely, 3 = Sometimes, 4 = Usually, 5 = Always.

To study the correlation among the features to start automatically profiling the users, we selected the 8 volunteers who had a higher adherence to the pilot during a time frame of 15 weeks in order to study the relationship between the features (see Fig. 3). In Fig. 4, the correlation matrix is shown. A weak but significant correlation is found between caffeine consumption and the time spent awake during the night by the users. Additionally, a negative weak correlation is found between the time spent awake and the citizen sleep satisfaction, which could indicate an indirect impact of caffeine consumption on sleep quality. Nevertheless, no correlation is found between caffeine consumption and onset time, although in the literature it has been shown that a delay should take place [8,14]. As expected [9], a correlation is found between the averaged time that a citizen goes to bed and the usage of electronic devices before bedtime. Overall, these results showed the usefulness of using questionnaire to detect bad sleep habits and finding ways of improving the sleep quality and satisfaction of the citizens, such as by recommending a reduction the caffeine consumption or the electronic devices usage before bedtime. However, the lack of strong significant relationships between the questionnaire answers and the sleep parameters lead into changes in the question wording. Stronger relationships are expected to be found during the next pilot, in accordance to what the literature states.

We also studied the impact of environmental factors (e.g., pollution concentration levels) in the sleeping activities. Unfortunately, preliminary experiments do not show any evidence.

Nutrition. Given the heterogeneity of nutritional habits, and the involvement of nutritional experts in the project, the Nutrition recommender system follows an expert-based approach following the specifications proposed by nutritionists from Eurecat. Its main objective is to provide recommendations based on the user profile to trigger behaviour change towards healthier nutritional behaviours, for example, increase fruit consumption or decrease salty food. It uses as input the food diary built from the pictures taken by users through their smartphone camera, and some questionnaires triggered at a convenient time throughout all the intervention. Based on the recipe coming from the LogMeal API, the recommender system computes the number of nutrients consumed by the user and the corresponding food groups contained on it, with the objective of calculating the adherence of the user to the corresponding behaviours. To do so, a nutritional database with more than 450 ingredients based on the CIQUAL[5] database was built and contains information about food groups and key nutrients. The results of these calculations are exploited with a rule-based reasoning (RBR) approach which decides what recommendations to be triggered during the intervention. The RBR bases its rules on the guidelines about food group intake specified by nutritionists. Aiming at not being very intrusive and repetitive, the Nutritional recommender system manages differently the required actions needed to be performed by the user, depending on the specific moment. The first week, the user is asked for taking pictures of all her/his meals, so that the behavioural and nutritional profile can be built. At the end of this phase, the nutritional objective of the user is set (e.g., increase fruit consumption) taking into account a) the food groups to work on, and b) distribution and types of recommendations. After

[5] https://ciqual.anses.fr/.

that, the user will be receiving personalised recommendations for 3 weeks with checkpoints each week to check the progression. In each checkpoint, the nutritional profile is updated with the new data coming from the past week, and the nutritional objective is adjusted accordingly. After one month, the user receives follow-up questions, so that the system can evaluate the progression and, if the system detects that the proposed behaviour has been adopted, it will propose the user to change to another objective. Figure 5 sketches the overall workflow.

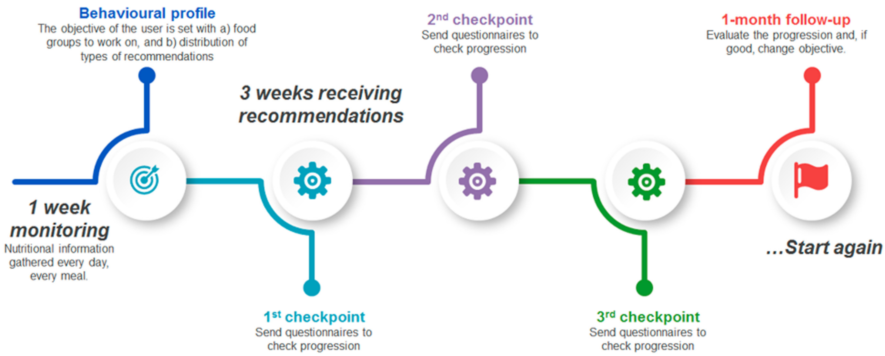

Fig. 5. The workflow adopted by the Nutrition recommender.

3 The Current Prototype

The CarpeDiem self-management system front-end is an app available in the Google Play (early access) for Android smartphones[6].

3.1 Data Collection

In its current version, the self-management system integrates all the devices and external sources described in Sect. 2.1:

- activity trackers from Fitbit[7] and Withings[8] for monitoring steps, sleeping habits, and energy expenditure;
- smart scales from Withings, for monitoring the weight and the BMI;
- LogMeal, for the automatic food recognition from pictures;
- Dark Sky API and Dades Obertes, for monitoring weather and air pollution, respectively.

[6] https://play.google.com/store/apps/details?id=com.eurecat.carpediem.
[7] https://www.fitbit.com/.
[8] https://www.withings.com/.

Users are asked to wear the wristband 24/7. Moreover, during the first week, they have also to take pictures to all the meals they eat. Finally, they have to fill, through the app, 3 questionnaires on her/his habits once a week and 1 more every day. The questionnaires are: SATED, about the satisfaction of the citizen regarding her/his sleep; Smoke, on the number of cigarettes smoked on average during the week; Use of technology, concerning the number of minutes spent on average using the smartphone or a tablet just before going to sleep; and Caffeine, to check the number of coffees, teas, and energy drinks the user drunk during the 7 h before going to sleep, the day before.

Feature(s)	Value	Frequency	Title	Modifier	Message
Steps	More than the goal	Daily (today)	Goal achieved	Generic	Congratulations! You have already exceeded your goal for today by 200 steps! Good job!
Steps	More than the goal	Daily (Today)	Goal achieved	Worst days	Congratulations! You have already reached your goal although it is Tuesday!
Steps	Less than the goal	Daily (Today)	Goal not achieved	Generic	Right now you are 7500 steps away to complete today's goal. Let's try to improve this tomorrow!
Steps	Less than the goal	Daily (Today)	Goal not achieved	Almost	Right now you are only 50 steps away to complete today's goal! You almost got it!
Steps	More than the goal	Daily (Yesterday)	Goal achieved	Generic	Congratulations! Yesterday you reached your goal, keep going!
Steps	More than the goal	Daily (Yesterday)	Goal achieved	Consecutive	Congratulations! Yesterday you achieved your goal for the last 5 consecutive days!
Steps	Less than the goal	Daily (Yesterday)	Goal not achieved	Generic	Yesterday you did not reach your goal, that means you have more energy to achieve it today!
Steps	Less than the goal	Daily (Yesterday)	Goal not achieved	Adverse weather	Right now you are 3000 steps away to complete today's goal, but we know it's because it is raining.
Steps	More than the goal on average	Monthly	New month, new goals!	None	We have noticed your performance has been awesome the past month, would you like to increase your goal?
Steps	Less than the goal on average	Monthly	New month, new goals!	None	We have noticed you have been struggling to keep up with your goal the past month, would you like to decrease your goal?

Fig. 6. Example of recommendations and nudges for improving the physical activity.

3.2 Nudges and Recommendations

Physical Activity. As described above, the Physical Activity recommender system sends nudges and recommendations considering the daily adherence and the adherence profile. Figure 6 shows some of the nudges and recommendations that have been defined. Some of them are totally generic and can be sent without considering the profile of the user. On the other hand, some others consider the day of the week (e.g., the "worst day"), the number of consecutive days the goal has (has not) been achieved, or the weather (e.g., a raining day). As shown in the Figure, monthly nudges are more oriented to suggest to change the goal depending on the overall trend of the last month.

Sleeping. For each cluster, together with the clinicians from the Biomedical Research Institute (IRB) in Lleida, we defined a suitable set of recommendations and nudges with the final goal of moving all the citizens in the healthiest cluster, corresponding to the number of hours suggested depending on the age, a sleep efficiency higher than 85%, and a satisfaction of 4 or 5 (i.e., normally or always satisfied). Recommendations and nudges on daily basis are based on the number of slept hours, the efficiency, the performed physical activity, and the questionnaire answers. Figure 7 shows an example of the nudges and recommendations that have been defined for each of the timing (daily, weekly, and monthly).

Feature(s)	Value	Frequency	Title	Message
Sleeping hours	Less than the minimum recommended hours	**Daily**	Not enough sleep!	Today you slept less than what is recommended. Try to sleep between 7 and 9 hours!
Satisfaction	Satisfaction "normally" (high) but less than the previous week	**Weekly**	Satisfaction worsening!	Your sleep satisfaction is high, but it is worsening! Pay attention to the sleep recommendations to improve it!
Sleep duration, Sleep efficiency, Satisfaction	Between the recommended hours Less than the threshold "Sometimes"	**Monthly**	You are doing a good job but there is room for improvement!	This month you slept the recommended hours, but we can still work together to improve your sleep satisfaction. Try to follow the advices to improve your sleep quality. If this is not enough, look for professional help.

Fig. 7. Example of recommendations and nudges for improving the sleeping activity.

Nutrition. Thanks to the expertise of Eurecat nutritionists, a database containing 130 recommendations of different types was constructed. Each of them is tagged with different labels (i.e. food group to increase/decrease, triggering time, and type of profile which it applies to). The database is used by the Nutritional recommender system to assure that the nutritional guidelines concerning food group consumption are met. The ones which frequency is daily and weekly, are automatically triggered through a scheduler at specific times manually specified. In contrast, the ones marked with "at a convenient time" frequency, are triggered through a rule-based reasoning system, which considers both the nutritional user profile and the recommendations already delivered. Figure 8 shows some of the nudges and recommendations that have been defined.

3.3 The Front-End

Figure 9 shows some screenshots of the app: (a) the home page where the user has an overview of her/his status and may answer to the questionnaires; (b) a list of received notification, each pillar represented by a different icon; (c) the setting page that shows, besides other information, that the app is linked to Fitbit; (d) the physical activity page with the summary of the steps a day that the goal was achieved; (e) the sleeping page with the summary of the current

Feature(s)	Value	Frequency	Title	Message
Daily food groups	Information about the consumption of the daily food groups.	**Daily**	These are the food groups detected today	An image with the food groups detected today, compared with the recommendations.
Weekly food groups	Information about the consumption of the weekly food groups.	**Weekly**	These are the food groups detected this week	An image with the food groups detected during the week, compared with the recommendations.
Diversity	Ideas to add diversity to the diet.	**At convenient time**	Increase vegetables and fruit consumption	Try to eat raw vegetables cooking recipes like tomato soup, mixed salads or vegetable snacks.
Hydratation	Water and other recommendations to keep the hydratation	**At convenient time**	Take an infusion!	Adding infusions or soups to your diet will help you to be more hydrated.
Reducing bad behaviours	Step by step reduction of bad behaviours	**At convenient time**	Add less sugar to your coffee	Try to add half of the usual quantity of sugar to your coffee!
Recipes	Recipes to cook specific food groups	**At convenient time**	Increase the vegetable consumption	Cook different vegetable recipes, for example: "https://www.directoalpaladar.com/recetas-de-legumbres-y-verduras/receta-de-ratatouille"
Healthy diet	Recommendations to follow a healthy diet	**At convenient time**	Cook home made desserts	Choose desserts cooked at home. For example, fruit salads.
Expertise	Explain important nutritional features	**At convenient time**		Make sure that, at lunch and dinner, there is a part of protein (legumes, fish, chicken, eggs, ...), grains (pasta, rice, quinoa, ...), and don't forget the vegetables!

Fig. 8. Example of recommendations and nudges for improving the nutritional habits.

weak showing the sleeping hours and the efficiency as calculated by Fitbit; and (f) an example of recognized food (meatballs).

3.4 The Pilot

On July 2020, a pilot started with 14 healthy volunteers that have been recruited in Eurecat (35.64 ± 8.58 years old; 5 females; and 22.96 ± 2.67 BMI). The pilot, which will end at the end of the year, has a threefold objective: (1) collecting feedback to improve the app and/or correct bugs; (2) testing the usability and evaluating the user experience; and (3) gathering new data to improve the 3 recommender systems and start implementing the holistic one. Results of the pilot will be calculated in terms of usability once the pilot ends.

4 Discussion

Self-management plays a central role in the P4 medicine paradigm, as it has a beneficial impact on both physical and psychological health status [10]. From a technological standpoint, personalisation, adaptation, and scalability are key

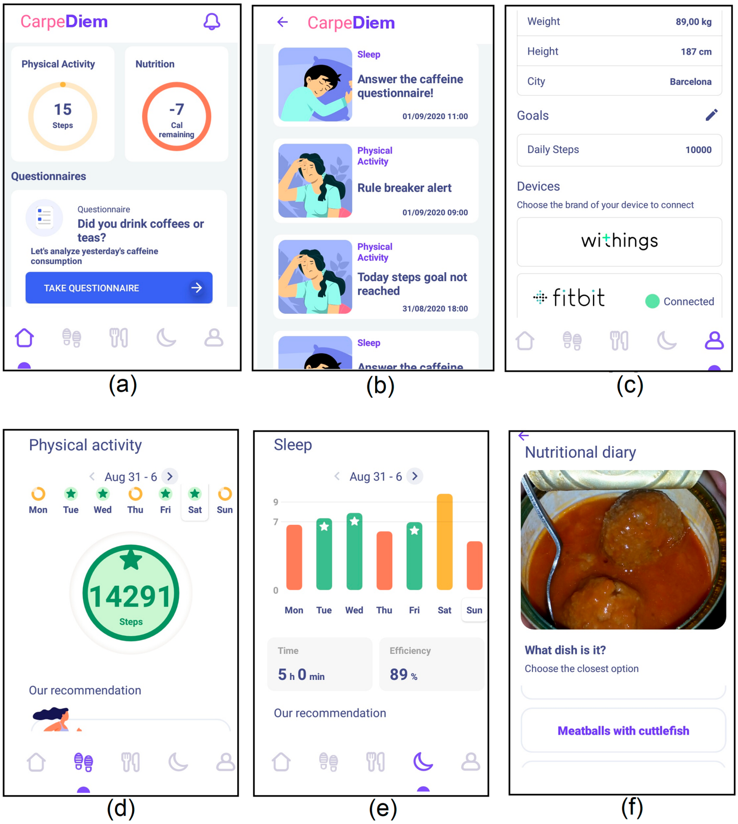

Fig. 9. The CarpeDiem app: (a) the main page with an overview of the activities; (b) a list of received notifications; (c) the setting page; (d) the physical activity details; (e) the sleeping activity details; (f) an example of food recognized by its picture.

properties to leverage when designing and developing software solutions promoting self-management through, for instance, patient empowerment [27]. One way of empowering patient so as to let them self-manage not only disease, in case of patients, but also day-to-day life, in case of any citizen, is to let them be aware of their healthy or unhealthy habits with the goal of, respectively, encourage them to improve or not. For instance, a common strategy regarding physical activity practicing is to provide regular reminders based on objectively measured levels of adherence [1]. This is true for both activities of healthy subjects and prescriptions to patients suffering of some chronic condition [26].

Many studies have shown that patients who engage in healthy diet, exercise, or other aspects of self-management have healthy benefits in terms of fewer symptoms, better functional capability, and fewer complications than those who do not in various diseases (e.g., HIV/AIDS [11], rheumatoid arthritis [24], asthma or chronic obstructive pulmonary disease [3], diabetes [31], and heart failure [20]).

Most relevant studies have examined the association between poor adjustment and poor self-management. On the other hand, there are studies that investigated the connection between good adjustment and engagement in self-management practices. These studies show evidence of a bidirectional association between wellbeing and adherence to self-management regimens. Citizens who can maintain good moods seem to be more willing to engage in lifestyle changes, and those who practice self-management behaviours also report improved wellbeing [12].

Mobile phones and other mobile information and communication technology applications and technologies hold great potential as a basis for powerful citizen-operated self-management tools. Apps for monitoring activities have been enthusiastically adopted by the general public. Most of the apps are linked to wearable devices (i.e., activity trackers) [13,21]. Activity trackers are capable of monitoring the daily activity of their users, in particular the number of steps, the heart rate, and the sleeping activity [16]. The counting steps module of the devices is based on the data from a 3-axis accelerometer. The steps are counted by using an algorithm which looks for intensity and motion patterns that are most indicative of people walking and running and includes algorithms to discard other acceleration movements as those produced by other transportation (e.g., cars, bus, train). The algorithm only counts a motion as a step if its duration is long enough. Some activity trackers measures also the heart rate considering blood volume changes produced by the heart beats. Automatic and continuous algorithms are normally applied to measure heart rate every minute. The algorithm that monitors the sleep activity is slightly different depending on the brand and the model. New generation activity trackers use the variability of the heart rate to estimate the sleep phases: light, deep, and REM. The sleeping activity data can be divided into summary variables and time series data. Similarly to CarpeDiem, apps that rely on activity trackers for monitoring activities focus on physical activities (e.g., steps, distance, and performed exercises), sleeping habits (number of sleeping hours and sleep phases), and, some of them, also nutrition (burned calories, food and drinks intake) and weight. Unfortunately, they are more based on monitoring activities than giving suggestions and recommendations to improve habits. Moreover, no personalisation is provided and only general nudges are given.

Apps specifically aimed at monitoring nutrition are also currently available in the market: for managing a daily food diary, track activities and lose weight successfully[9]; for registring or for scanning food care products to decipher their ingredients and evaluate their impact on your health[10,11]. Unfortunately, those solutions continuously need the manual intervention from the user that stops using them.

CarpeDiem advances current solutions because it is an IoT solution that fuses together data from different sources and, considering the profile of each user, provides personalized recommendations and nudges. Moreover, it considers not only

[9] https://play.google.com/store/apps/details?id=com.yazio.android.

[10] https://play.google.com/store/apps/details?id=io.yuka.android.

[11] https://myrealfood.app/.

data from an activity tracker or manually input by the user (i.e., questionnaires or food images), but also environmental data that may influence daily life activities. Thus, CarpeDiem takes into account preferences, habits, weather conditions, and further data when compiling recommendations and nudges. Currently, CarpeDiem provides support to healthy people that want to follow healthy habits. Next versions of the system will allow also to follow a plan for reducing weight, improving training, or having a plan specialized for a specific need (e.g., elderly adults or chronic patients).

5 Conclusions and Future Directions

This paper presented the CarpeDiem self-management system, an IoT solution aimed at providing intelligent and automatic support to people who want to follow a diet to lose weight, or to maintain a healthy lifestyle. The CarpeDiem approach integrates smart devices and open data sources, as well as input from the user. It monitors physical- and sleeping-activity, nutrition, as well as environmental data and lifestyle habits, and provides personalised recommendations and nudges. The first prototype of the system is available for Android and 14 healthy users are currently testing it.

As for the future directions, we will start first from the feedback we are receiving from the volunteers. In particular, we will improve the nutrition monitoring allowing the volunteers to select suggested recipes or to upload their owns. They will be allowed also to specify the size of the dish. The smartphone will be used also to detect the luminosity of the bedroom during the sleeping time and the citizen will be asked regarding the comfort of the bed, since especially vulnerable or at risk citizens often sleep on truly old or uncomfortable beds. Furthermore, data gathered from the pilot will be used to re-train the models of the recommender systems improving them. From those data, we will investigate and develop also an holistic recommender system that considers all the pillars together to give more personalised recommendations that take into account all the lifestyle habits together. Collaborative approaches will be also followed to consider similarities among citizens in order to send recommendations and nudges, adding also gamification. Finally, mindfulness, the fourth pillar of the health, will be also considered to give support to the citizens in managing anxiety and stress, as well as improve sleeping quality.

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References

1. den Akkera, H., Cabrita, M., den Akker, R., Jones, V.M., Hermens, H.J.: Tailored motivational message generation: a model and practical framework for real-time physical activity coaching. J. Biomed. Inform. **55**, 104–115 (2015)
2. Alderson, M., Starr, L., Gow, S., Moreland, J.: The program for rheumatic independent self-management: a pilot evaluation. Clin. Rheumatol. **18**(4), 283–292 (1999). https://doi.org/10.1007/s100670050103
3. Bailey, W.C., et al.: Asthma self-management: do patient education programs always have an impact? Arch. Intern. Med. **159**(20), 2422–2428 (1999)
4. Barlow, J., Wright, C., Sheasby, J., Turner, A., Hainsworth, J.: Self-management approaches for people with chronic conditions: a review. Patient Educ. Couns. **48**(2), 177–187 (2002)
5. Barrett, M.J.: Patient self-management tools: an overview. California HealthCare Foundation (2005)
6. Benítez, I., et al.: Validation of the satisfaction, alertness, timing, efficiency and duration (SATED) questionnaire for sleep health measurement. Ann. Am. Thorac. Soc. **17**(3), 338–343 (2020)
7. Bolaños, M., Valdivia, M., Radeva, P.: Where and what am i eating? Image-based food menu recognition. In: Leal-Taixé, L., Roth, S. (eds.) ECCV 2018. LNCS, vol. 11134, pp. 590–605. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-11024-6_45
8. Burke, T.M., et al.: Effects of caffeine on the human circadian clock in vivo and in vitro. Sci. Transl. Med. **7**(305), 305ra146 (2015)
9. Calamaro, C.J., Yang, K., Ratcliffe, S., Chasens, E.R.: Wired at a young age: the effect of caffeine and technology on sleep duration and body mass index in school-aged children. J. Pediatr. Health Care **26**(4), 276–282 (2012)
10. Clark, N.M., Becker, M.H., Janz, N.K., Lorig, K., Rakowski, W., Anderson, L.: Self-management of chronic disease by older adults: a review and questions for research. J. Aging Health **3**(1), 3–27 (1991)
11. Collins, R.L., et al.: Changes in health-promoting behavior following diagnosis with HIV: prevalence and correlates in a national probability sample. Health Psychol. **20**(5), 351 (2001)
12. De Ridder, D., Geenen, R., Kuijer, R., van Middendorp, H.: Psychological adjustment to chronic disease. The Lancet **372**(9634), 246–255 (2008)
13. Diaz, K.M., et al.: Fitbit®: an accurate and reliable device for wireless physical activity tracking. Int. J. Cardiol. **185**, 138–140 (2015)
14. Drake, C., Roehrs, T., Shambroom, J., Roth, T.: Caffeine effects on sleep taken 0, 3, or 6 hours before going to bed. J. Clin. Sleep Med. **9**(11), 1195–1200 (2013)
15. Endicott, J., Nee, J., Harrison, W., Blumenthal, R.: Quality of life enjoyment and satisfaction questionnaire: a new measure. Psychopharmacol. Bull. **29**(2), 321–326 (1993)
16. Feehan, L.M., et al.: Accuracy of Fitbit devices: systematic review and narrative syntheses of quantitative data. JMIR Mhealth Uhealth **6**(8), e10527 (2018)
17. Fernández, J.M., et al.: Towards argumentation-based recommendations for personalised patient empowerment. In: International Workshop on Health Recommender Systems, Co-Located with ACM RecSys 2017 (2017)
18. Hirshkowitz, M., et al.: National sleep foundation's sleep time duration recommendations: methodology and results summary. Sleep Health **1**(1), 40–43 (2015)

19. Hood, L., Friend, S.H.: Predictive, personalized, preventive, participatory (P4) cancer medicine. Nat. Rev. Clin. Oncol. **8**(3), 184–187 (2011)
20. Jaarsma, T., Halfens, R., Tan, F., Abu-Saad, H.H., Dracup, K., Diederiks, J.: Self-care and quality of life in patients with advanced heart failure: the effect of a supportive educational intervention. Heart Lung J. Acute Crit. Care **29**(5), 319–330 (2000)
21. Meyer, J., Boll, S.: Digital health devices for everyone! IEEE Pervasive Comput. **13**(2), 10–13 (2014)
22. Nakagawa-Kogan, H., Garber, A., Jarrett, M., Egan, K.J., Hendershot, S.: Self-management of hypertension: predictors of success in diastolic blood pressure reduction. Res. Nurs. Health **11**(2), 105–115 (1988)
23. Ohayon, M., et al.: National sleep foundation's sleep quality recommendations: first report. Sleep Health **3**(1), 6–19 (2017)
24. Riemsma, R.P., Taal, E., Kirwan, J.R., Rasker, J.J.: Systematic review of rheumatoid arthritis patient education. Arthritis Care Res. **51**(6), 1045–1059 (2004)
25. Ross, J., Stevenson, F., Lau, R., Murray, E.: Factors that influence the implementation of e-health: a systematic review of systematic reviews (an update). Implement. Sci. **11**(1) (2016). Article number: 146
26. Tabak, M., Op den Akker, H., Hermens, H.: Motivational cues as real-time feedback for changing daily activity behavior of patients with COPD. Patient Educ. Couns. **94**(3), 372–378 (2014)
27. Tomes, N.: Patient empowerment and the dilemmas of late-modern medicalisation. The Lancet **369**(9562), 698–700 (2007)
28. Vargiu, E.: From healthy to happy ageing: the power of self-management. In: AI*AAL.it 2017. Artificial Intelligence for Ambient Assisted Living. Proceedings of the Third Italian Workshop on Artificial Intelligence for Ambient Assisted Living, CEUR Proceedings, vol. 2061 (2018)
29. Vargiu, E., Fernández, J.M., Gonzales-Gonzales, M., Morales-Garzón, J.M., Prunera-Moreda, K., Miralles, F.: A self-management system for complex chronic patients. Int. J. Integr. Care (IJIC) **19**, 1–2 (2019)
30. Vargiu, E., Zambrana, C., Targa, A., Barbé, F.: Improving sleeping habits: preliminary experiments in Barcelona and Lleida. In: AI* AAL@ AI* IA, pp. 51–65 (2019)
31. Williams, G.C., McGregor, H.A., Zeldman, A., Freedman, Z.R., Deci, E.L.: Testing a self-determination theory process model for promoting glycemic control through diabetes self-management. Health Psychol. **23**(1), 58 (2004)