Enabling Patient Adherence via Personalised, Just-in Time Adaptive Interventions in ADLIFE Architecture

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ABSTRACT

Chronic diseases introduce challenges for the patients to continuously be involved in their care activities and manage the changing requirements of their disease. Patient empowerment activities are a critical component to assist patients in their long-term care journey. In the ADLIFE project (H2020, SC1-DTH-11-2019, 875209), an integrated care planning approach is used where patients are assigned various care plan activities by multidisciplinary care teams. To increase patients' adherence to the care plan, a continuous behavioral monitoring architecture is developed for delivering digital personalised, just-in time adaptive interventions.

CCS CONCEPTS

• **Information systems** → **Computing platforms**.

KEYWORDS

Patient Empowerment, Just-in time Adaptive Interventions, Continuous behaviour monitoring

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1 INTRODUCTION

Chronic diseases are recognized as major causes of disability and mortality and major source of healthcare costs [6]. Chronic diseases introduce demanding challenges for the patients as well [14]: chronic diseases have the potential to worsen their quality of life by limiting their capacity to live well, their functional status, and productivity. Successful long-term care of patients with chronic conditions requires active patient self-management and a proactive involvement of patients in their healthcare and treatment [8]. Patients suffering from chronic diseases have important responsibilities including making significant lifestyle changes such as following a strict diet and exercise plan, adherence to complex treatment regimens, managing medications, monitoring themselves and reacting in case of problems [12, 13, 15].

In the ADLIFE project (H2020, SC1-DTH-11-2019, 875209) [1], an integrated care planning approach is implemented where patients suffering from chronic heart failure and/or Chronic obstructive pulmonary disease (COPD) are assigned various care plan activities by multidisciplinary care teams. As a part of their care plan, patients need to engage in several different self-management activities. They need to adhere to their medication regimens, they need to often modify more than one healthy behaviour at a time such as complying with dietary plans, performing physical exercises, and they need to carry out several different tasks assigned to them, such as self-weight measurements and filling-in questionnaires to report symptoms and provide Patient Reported Outcome Measures (PROMs). To support the patient in following and adhering to their care plans, ADLIFE provides a Patient Empowerment Platform (PEP) to patients and their informal care givers, as a means to reinforce their capacity to take control of their circumstances, exercise power to achieve their care plan goals and to be actively involved in the implementation of their care plan. In the ADLIFE PEP, patient empowerment is facilitated through a suite of mechanisms including sharing care plan clearly with patients and his/her informal care givers, feedback from patient is enabled via Patient Reported Outcome Measures (PROMs), symptom data collection, care plan feedbacks and patient recorded data, presentation of educational materials and shared decision making tools [4, 7].

In addition to presenting a clear view of care plan responsibilities, ADLIFE PEP supports the patients in their self-management journey, via Just-in-time Adaptive Interventions (JTAI). JTAI is an intervention design aiming to provide the right type/amount of support, at the right time, by adapting to an individual's changing internal and contextual state. JTAIs are used in ADLIFE to remind patients about the activities that are assigned to them as a part of their care plan, and to motivate them to reinforce their adherence. Studies have shown that such interventions addressing common behavioural risk factors for chronic diseases such as tobacco smoking, poor diet, and physical inactivity and supporting behaviour change for the effective self-management of chronic conditions can positively contribute to health and well-being of the patients with chronic conditions [10]. The NICE guideline on "Behaviour change" [9], reports that "there is overwhelming evidence that changing people's health-related behaviour can have a major impact on some of the largest causes of mortality and morbidity, and to alter current patterns of chronic diseases".

In ADLIFE PEP, delivering digital personalised, just-in time adaptive interventions is achieved via a continuous behavioral monitoring architecture [2, 5]. Continuous behavioral monitoring necessitates real-time tracking of a patient's care plan activity achievements, through various sources of data, such as measurements from medical devices, electronic health records and the feedback via ADLIFE PEP app used by the patient. In this paper, we introduce the technical details of the JTAI delivery engine, in particular the continuous behavioral monitoring architecture.

2 JUST-IN TIME ADAPTIVE INTERVENTION DELIVERY ENGINE

ADLIFE provides Personalized Care Plan Management Platform (PCPMP) for the healthcare professionals (HCP) to monitor and manage patients' care plan. Using the PCPMP, HCPs can assign goals (such as increasing physical activity), patient activities (e.g., self-measurement of weight), questionnaires (such as drug side effect questionnaires, symptom reporting questionnaires, standard score-based assessments of quality of care environment (PCQ-P) [3]), educational materials and prescribe medications to the patients. The patients can see their care plans, respond to the assigned activities and questionnaires, record measurements or report taken medications using the Patient Empowerment Platform (PEP) [7]. These two complementary platforms are integrated over an HL7 FHIR standard based repository, onFHIR [4, 11]. The FHIR resources to represent the care plan and its components are profiled as presented in Table 1.

Once a care plan is created for the patient via the PCPMP, it is automatically shared with the PEP via the shared FHIR repository. Then the patients can review their care plan in detail via user friendly mobile and Web based interfaces. Using the PEP, the patients can also provide data related to their care plan activities. They can submit self-measurements, report performed activities or taken medications. These are stored as Observation FHIR resources in the shared repository. The patients can also respond to the questionnaires assigned to them in PEP which are stored as *QuestionnaireResponse* resources in the shared FHIR repository.

As a part of their care plan, the patients may be requested to perform some of the activities assigned to them in a specified time frame. Such patient activities may be "walking 1 km per day", "measuring blood pressure twice a day" or "submitting meal photo of your dinner once a day". Similarly, patients may be asked to respond to a questionnaire about a daily routine every day. Within a care plan, the frequencies of these recurring activities are represented in a structured manner via the Timing data element of HL7 FHIR. The JTAI engine processes these timings to know how frequently an activity is expected to be performed, keeps track of the observations that are submitted by PEP showing to what extent the patient performs these activities and calculates the performance of the patient in adhering his/her care plan.

ADLIFE JTAI engine provides motivative interventions to the patients based on their calculated performances in adhering to their care plans. The content of these interventions has been identified

Table 1: FHIR Resources used for representing Care Plan Components

Component	FHIR Resource	Description
Care Plan	CarePlan	Care plan of the patient
Goal	Goal	Targeted treatment outcomes
Appointment	Appointment	Scheduled appointments between care team members and patients
Referral	ServiceRequest (category=referral)	Referral of the patient to another service
Medication	MedicationRequest	Prescribed medications of the patient
Patient Order	ServiceRequest (category=patient-order)	Assigned activities to be performed by the patient
Patient Reported Outcome Measures (PROMs)	Questionnaire & QuestionnaireResponse	Questionnaires to collect information about the treatment outcomes from the patients
Education Materials	CommunicationRequest	Educational materials such as multimedia or written documents about diseases, medication usage, diet, etc.

by the clinical reference groups (CRGs) of the ADLIFE partners using four main Behavior Change Techniques (BCTs):

- General reinforcement: General motivational messages such as "Good work! You reached your goal for the day".
- Positive comparison with self: Here, we compare patient's recent performance in carrying out the assigned activity, with one of his/her previous performance. e.g.: "That was a good day, you are 50% better than last Tuesday (your best day last week) in blood glucose monitoring."
- Positive comparison with other patients in the cohort: Here, we compare patient's recent performance in carrying out the assigned activity, with the average performance of the patient cohort, to motivate the patient. e.g.: "Good work! Your performance in daily exercise is better than 60% of other patients in the cohort this week."
- Simple reminders: e.g., "Don't forget to complete your Daily Mood Questionnaire today!"

In ADLIFE architecture, JTAIs are designed to be delivered when an opportune moment is detected to remind and motivate the patient. The JTAIs are triggered after certain events are detected by the platform:

- Whenever a planned activity in the patient's care plan has happened, for example the patient logged a walking exercise, his/her current performance to achieve his daily/weekly/monthly goal is calculated, and he is provided positive feedback and reinforcement.
- Whenever a planned activity missed, e.g., the patient has missed to record his daily BP measurement, his/her current performance to achieve his daily/weekly/monthly goal is calculated, and he is provided positive feedback and reinforcement.
- Before planned events, especially when the activity is not a periodic one but a singular activity to be carried out at a certain time slot, e.g., control appointment with his GP, the patient is provided reminder messages.

The system continuously monitors patient's activities in the PEP at the background, to catch a convenient moment to send reminders and motivational messages as interventions. The system calculates patient's performance daily/weekly/monthly in the background and categorizes them as follows:

- TARGET ACHIEVED: Patient achieves daily, weekly or monthly target (X% of the targeted activities. e.g., 100%)
- TARGET SUCCESSIVELY ACHIEVED: Patient successively reached his daily, weekly or monthly targets for a number of times
- TARGET CLOSE TO ACHIEVE: Patient is very close to achieving his daily, weekly or monthly target and there is still time to achieve it fully (s/he has achieved X% of the targeted activities. e.g. 70%)
- TARGET IN PROGRESS: Patient has completed a certain percentage of his targeted activities but has not yet completed it. Example: Patient needs to walk three times a week, has performed some exercise (s/he has walked two times this week), the week is not over yet, and the patient has still time to meet his/her weekly target
- TARGET ALMOST ACHIEVED: Patient could not meet his/her targets for the day/week/month but was very close to achieve. Example: Patient needs to walk three times a week, has performed some exercise (s/he has walked two times this week), yet, the week is over.
- TARGET NOT ACHIEVED: Patient could not meet his/her targets for the day/week/month, and s/he was not close to achieving it.

Based on these, different rule-based JTAI content templates have been prepared. Some examples are provided in Table 2. The achievement percentages can be individually calculated, and the content is adapted individually for the patient dynamically.

Table 2: Example rule definition for defining the JTAI content to be delivered when "Target is achieved"

Main BCT Technique	Intervention Content ([lang=en])	Examples
General reinforcement	Good work! You reached your target for the ${target_temporal}.	Good work! You reached your target for the day.
Positive comparison with self	That was a good ${target_temporal}, you are ${comparison_value}% better than ${comparison_temporal} in self blood pressure monitoring!	That was a good day, you are 30% better than last Tuesday (your best day last week) in self blood pressure monitoring!
Positive comparison with others	Good work! Your performance is better than ${comparison_population_percentage}% of others ${comparison_temporal}.	Good work! Your performance is better than 40% of others this week.
General reinforcement	Thank you for sending in your readings, it is much appreciated.	Thank you for sending in your readings, it is much appreciated.

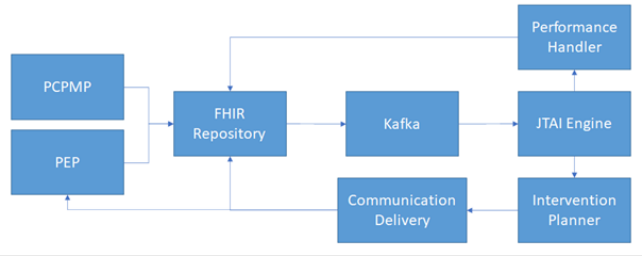

Figure 1: ADLIFE JTAI Delivery Architecture

```
{
  "behaviour":  "walking",
  "observations": [
    {
      "system":"http://snomed.info/sct",
      "code": "129006008"
    }
  ]
}
```

Figure 2: Walking activity profiled as a behaviour in reference to the SNOMED-CT terminology

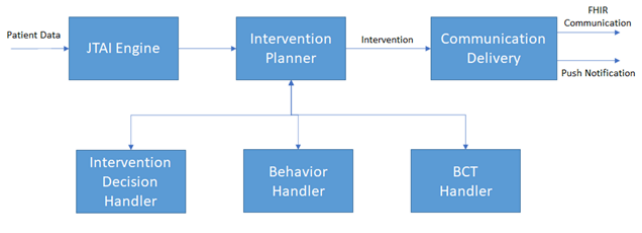

Figure 3: Details of Intervention Planning Approach

```
{
  "id": "ADLIFE-MOT-GCA-PCS-1",
  "description": "Patient is close to achieve his
  monthly or weekly goal, so we motivate him to go on
  with comparing with thyself",
  "category": "motivation",
  "bct": "pcs",
  "rules": [
    "goal.monthly = 2",
    "goal.weekly = 2"
  ],
  "content": {
    "en": "You are almost there for ${goal_temporal}!
    Just keep up your good work, and you will exceed
    your ${comparison_simulation_temporal}'s performance
    in ${behavior} with ${comparison_simulation_value}%."
  }
}
```

Figure 4: An example self-comparison motivational intervention content rule

2.1 Detailed description of JTAI Delivery Architecture

As depicted in Figure 1, PCPMP and PEP are integrated with the onFHIR repository over RESTful APIs. PCPMP creates or updates care plan activities and goals whereas PEP creates observations reporting achievement of these goals and activities by patients, records questionnaire responses, etc. The JTAI Engine is subscribed to the FHIR Repository over Kafka to receive and process the changes and run the intervention flow when necessary. When an activity is created by the PCPMP, JTAI Engine catches this event over Kafka, transforms it to its internal data model by matching a *Behaviour* and creating a *BehaviorState* with the target and timing information.

The behaviors are predefined in a coded way to enable machine processing of semantic concepts and included in the rule-based templates of the JTAI Engine. For example, walking activity is profiled from the SNOMED-CT terminology as shown in Figure 2.

When a patient submits data through the PEP, the JTAI Engine tries to match it with a behavior. If the code of the reported Observation by PEP matches a predefined behavior, the JTAI Engine passes them to the *Performance Handler*. The related activity's daily,

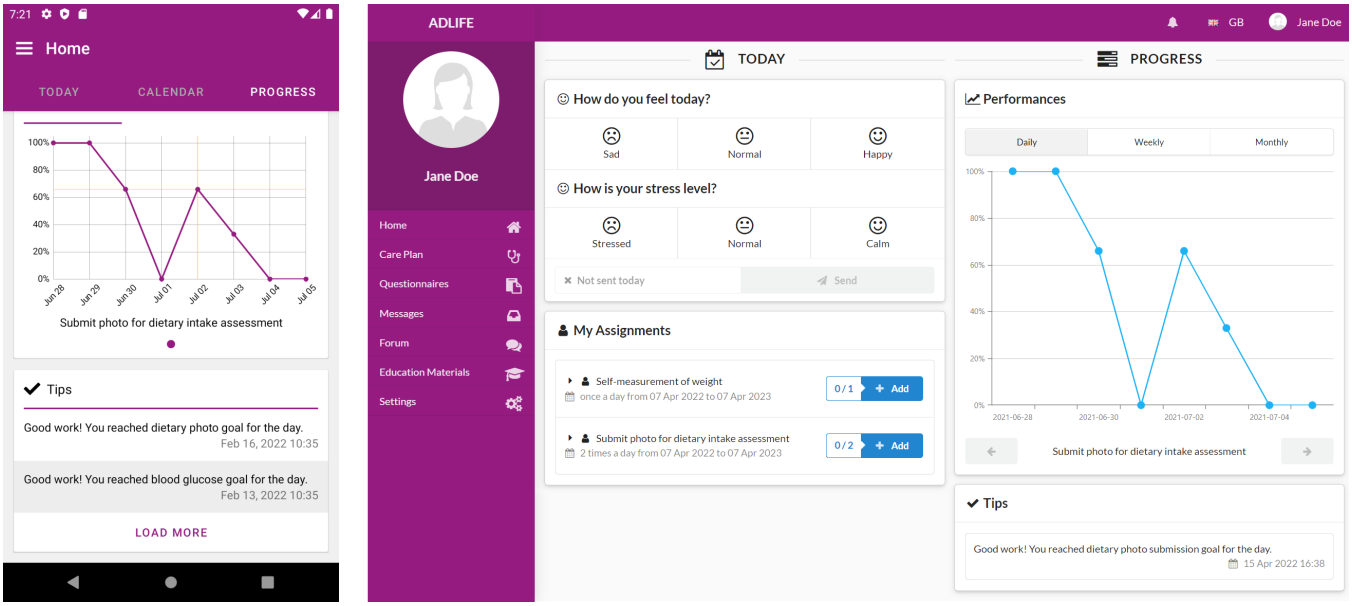

Figure 5: Screenshots from the mobile and Web PEP Interfaces presenting adherence performances and JTAIs as tips

weekly and monthly performance is re-calculated to be used in comparison-based interventions and stored in the onFHIR repository.

Then, the intervention decision flow is triggered by the *Intervention Planner* according to the performance, communication preferences of the patient (such as notification frequency) and the needs of the different pilot sites as depicted in Figure 3.

The *Behavior Handler* as a part of *Intervention Planner* evaluates the rules from the JTAI content templates (Table 2) to see if the current state is suitable for an intervention. An example self-comparison motivational intervention content rule can be defined as shown in Figure 4.

This intervention is defined to send a motivational message to a patient when their performance in the current month or week is better than the previous period. The behaviour change technique (BCT) is set to "Positive Comparison with Self" (pcs), and the "goal.period = 2" rules mean that monthly or weekly goal should be about to achieved. BCT Handler evaluates if the rules are satisfied, and previous month's/week's performance is compared with the current ones to see if a positive comparison is suitable. If there has been an improvement relative to the previous period when the goal is achieved, the intervention delivery rule is fired. There might be more than one suitable intervention for the current progress of the patient. In this case, the intervention with higher priority will be decided by the BCT Handler if applicable. These priorities are defined as a part of the configuration. Otherwise, an intervention will be chosen randomly.

After the intervention is decided, it is recorded in the FHIR repository as *Communication* resource by the *Communication Delivery* component to be shown as a notification in the PEP web application. The PEP application which has previously subscribed to receive notifications whenever a new Communication resource for a particular patient is stored, is triggered by onFHIR Subscription system, which then delivers the notification to the user via the PEP Web application as a motivational tip. The intervention is also sent as push notification to the mobile PEP application using Google Firebase API. Sample screenshots from mobile and Web PEP applications presenting adherence performances and JTAIs as tips are depicted in Figure 5.

3 CONCLUSIONS

In this paper we presented our research results about how self-motivation and behavioral change interventions can be implemented in a standard based approach based on HL7 FHIR, and presented the details of continuous behavioral monitoring architecture on FHIR Repository to enable delivery of adaptive interventions. The contributions of this paper are demonstrating that real-time tracking of a patient's care plan activity achievements can be successfully implemented on an HL7 FHIR based care plan management architecture, and introducing the respective data model for behavior monitoring and JTAI content and also presentation of JTAI delivery architecture. The technical architecture of the continuous behavioral monitoring platform and JTAI delivery engine and the intervention delivery rules are ready to be piloted. Within the scope of the ADLIFE project, the system and its integration with care planning systems will be validated in seven pilot sites involving 577 healthcare professionals from 75 different hospitals, clinics and primary care services. The usability and acceptance of the technology, by patients, and the effectiveness of the behavioral interventions on patient's adherence will be assessed during pilot studies with 882 patients and 1243 caregivers.

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