Ontology Based Context Fusion for Behavior Analysis and Prediction

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Abstract. Current healthcare systems facilitate patients in provision of healthcare services by using their context information. However, the problem is that the context information received from various sources is of heterogeneous nature which is not useful for conventional systems. To overcome this issue, we propose an ontology-based context fusion framework in this research that fuses the related and relevant context information collected about the patient's daily life activities for better understanding of patient's situation and behavior. The fused context information is logged using ontological representation in Life Log deployed on cloud server. On top of the Life Log, behavior analysis and prediction services are developed to analyze the behavior of the patient and provide better healthcare, wellness, and behavior prediction services. System execution flow is demonstrated using a running case study that shows how the overall process is initialized and performed.

Keywords: u-Healthcare, Lifestyle, Activity Recognition, Ontology, Context-awareness, Context Fusion

1 Introduction

During the last couple of decades, the emergence of new technologies in the field of healthcare has shown tremendous improvement in healthcare and lifestyle of a person [5, 13]. In response to the needs, the use of smartphones and smartphone-based healthcare applications are increasing at a rapid pace [5, 12]. Activity recognition using such applications [12] is an example that is developed to analyze, recognize, and monitor the daily activities of a person [5, 12]. Other examples include healthcare systems to monitor health issues, nutrition intakes and social networks to keep track of social interactions of patient (user) [1, 5, 9, 12, 13]. The key to success in improving the lifestyle of a patient is to understand his/her behavior first. The services like personalized lifecare, recommendations, and behavior analysis can be provided by using the advanced technologies for capturing and fusing the context information like activity information, social interaction, diet and environment information.

Healthcare systems have been at the top due to its everlasting importance in our daily life. It is reported that 68% of the healthcare cost in USA is due to the poor lifestyle of people. So there is a need of a system that can reduce the cost of healthcare services at both hospitals and home environment by integrating different context information emerging from diverse modalities in order to use them for

behavior analysis, behavior recommendation and behavior prediction to facilitate patients and caregivers in provisioning of lifecare services.

The solution proposed to the above problems is to fuse the daily life context information of a patient coming from various sources and build patient's profile based on the emerging context information. The build profile is then used for behavior analysis, and prediction to attain better lifestyle. In order to fuse the context information received from various diverse sources (i.e., physical activities, social media interactions, diet information, and environment information), ontology based context fusion (horizontal and vertical) mechanisms are developed to fuse patient's context information at different time intervals of a day. As shown in Fig 1, the context information is collected using smartphone and then forwarded to the main system deployed on cloud. The fused context information is then logged in a centralized ontology based Life Log. On top of Life Log, a behavior prediction algorithm is proposed in this research to predict patient's behavior based on their profile, current context and the existing behavior models stored in the Life Log repository.

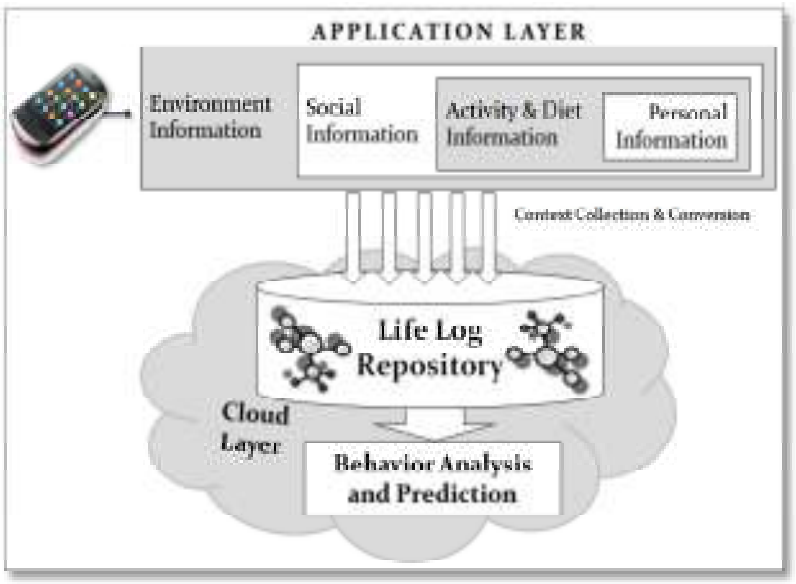

Fig. 1. Overview of the proposed solution

The research paper is arranged as follows: Section 2 describes the related research work in the area of healthcare and behavior analysis. Section 3 presents our proposed system with details on each component. Section 4 presents a case study as a working example of our proposed system. Section 5 concludes the research work and provides future research directions.

2 Related work

Research in the area of healthcare using information technology is getting mature where various healthcare and wellness services are provided remotely [5, 12, 13]. In this area, ComMotion [1] and HYCARE [2] are activity reminding systems based on predefined schedule. Both these systems recognize human activities with the help of sensors and generate alerts for scheduled activities. Most recently an ontology-based reminder system [4] is developed that incorporates rules to manipulate the recognized activities of elderly persons. Some authors have focused on recognizing patient's real time activities using low-level sensory data coming from diverse sensors. In [7], the authors have used the information about activities recognized and the domain knowledge to analyze the situation with the help of experts designed rules. The research work in [6, 11] has focused on the social interaction of patients.

The context information collected is necessary for comprehensive and sophisticated recommendations generation; however, it is also a challenge to keep the context information in uniform representation and also relate (fuse) them to appropriate user [4]. The need of context representation and fusion is highlighted with the help of their uses in [4, 7]. Every context-aware system needs to formally represent the context after acquisition and fuse them with other relevant context if needed. In case of multiple and diverse sensors discussed in [4, 7, 13], the context from one sensor needs to be fused with other sensor's context to achieve a higher level context with more confidence on the monitored situation [5, 7, 13]. However, these systems are strict in representations and only consider multiple sensors of similar type.

The fused context is then logged in Life Log where all information about a patient life is logged. Patients and caregivers can refer back to any of the contents in the log easily and intelligently. The system in [14] has initially developed Life Log system and allowed users to build and exploit Life Log ontology. Microsoft research project MyLifeBits [9] stores the life activities of a person with the help of SenseCam that contains sensors like accelerometers, heat sensor and audio sensor. It provides a clear and understandable view of user's life and history which is a step towards user's behavior analysis. The logged context retrieved from diverse sources has potential to be used for behavior analysis and user's lifestyle monitoring. Morita [10] has developed a behavior monitoring system to capture user's interests from large amount of context information, whereas in [2], the authors have explained different limitations regarding recommendations generation using life log. To overcome these limitations, they made suggestions to provide support in the process by introducing multiple context resources. In [8], the authors presented behavior ontology to capture user behavior within a given context (i.e., time period and community) and used a semantic-rule based methodology to infer the role a user has within a community based on his/her exhibited behavior. The work has facilitated in analyzing the differences between communities and predicting community activities. In [12], the authors monitored daily activities of user for long term and then mine some irregular lifestyle patterns which can affect user health.

The main limitations of the existing systems are that majority of them uses one input modality for human activities and are not based on context information extracted from diverse input sources. Moreover, the existing developed systems are based on imperfect context information [3] which is the main cause of irregular service recommendation and decision making.

3 Proposed system

To provide better healthcare and lifestyle services, we need to understand the behavior of patient first. Current state of the art technologies are matured enough to help us in collecting patient's daily life routine information which can be later on processed to generate the required services. The proposed system architecture comprises of two main components as shown in Fig 2 and discussed below.

3.1 Context Modeling

Context modeling component is responsible for collecting and modeling the context information in a unified format in order to be used by Behavior Modeling & Prediction component to analyze and predict patient's behavior. The proposed system collects patient's 1) profile information, 2) social media interactions, 3) diet information, 4) daily life activities information and 5) environment information from various sources using our lab developed systems [12, 13, 15]. To store the context information collected, an ontology-based Life Log repository is maintained in the system to provide basic descriptions for events, experiences, actions, activities and interactions. The goal of Life Log is to record and archive all information about a patient's life. The collected context information is converted into a unified representational format acceptable by Life Log using the context conversion algorithms.

The logged context passes through the structural and semantic verification processes to check the information received for acceptable format and semantic conflicts if any. The relatedness and dependency of context information is achieved in proposed system by using the proposed context fusion (horizontal and vertical) mechanism. For example, context information like *walking, bending, sitting, standing* together is used for exercise if we apply horizontal fusion technique with specified time intervals. Similarly, a tweet "*exercise is good for health*" by a patient, and then after sometimes, performing exercise by the same patient means there exists some relationship between the tweet and the performed activity. So these contexts need to be fused in order to understand patient's interest and behavior in exercise.

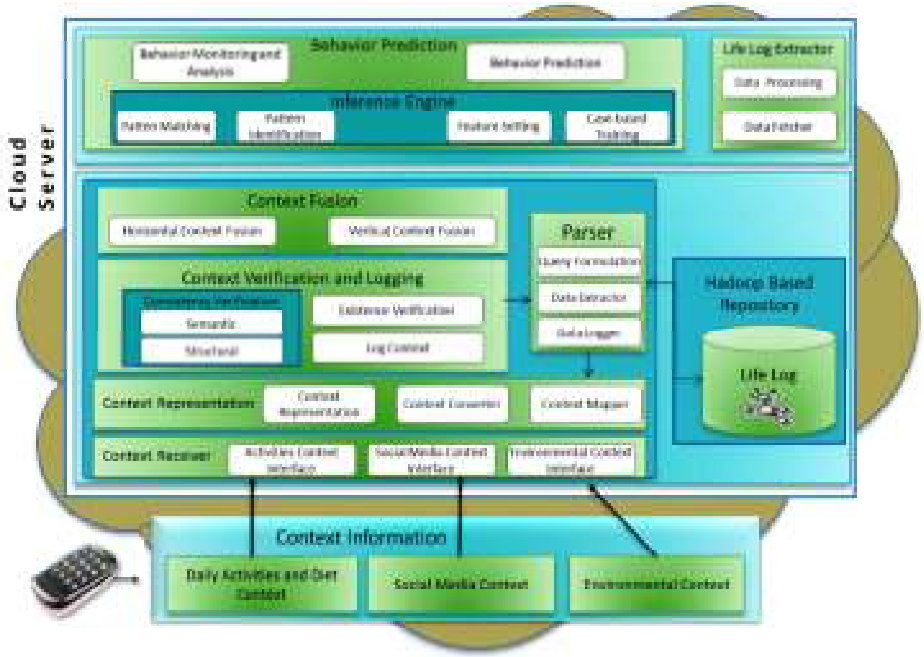

Fig. 2. Architecture of proposed system

3.2 Behavior Modeling and Prediction

This component analyzes and predicts the behavior of a patient using patient's profile from Life Log repository. Initially, patterns are identified in the profile and context information which are then matched against pre-classified patterns. In case of patient with abnormal life patterns, such situation is detected by system using pattern classification that patient behavior is not according to the prescribed behavior. This result can be viewed for both patient's recent past (short term) as well as patient's behavior pattern for a longer duration (long term) of time. This also facilitates patients and caregivers in analyzing patient's lifestyle. For the purpose of prediction, case-based reasoning scheme is used in the proposed system that first identifies prominent features in patient's context and then match against various trained behavior models. A match of patient activity, context and behavior results in prediction for the possibility of patient behavior in immediate future.

4 Case Study

In this section, we show the execution flow of proposed system with a running case study. Table 1 shows the context information received by proposed system regarding patient's daily life routine activities emerging from different sources [1, 5, 12, 13, 15]. Location sensor recognizes the patient in a restaurant at 14:00:00. Using smartphone,

patient's eating activity is recognized which has resulted in increase of patient calories consumption at 14:05:00 and 14:15:00 respectively.

Table 1. Context information received from various sources

<activity type="Motion"> <detectedBy> Location Sensor </detectedBy> <hasName> Truc </hasName> <activityName> In Restaurant </activityName> <id> 666 </id> <time> 14:00:00 </time> </activity>	<activity type="Motion"> <detectedBy> Body Sensor </detectedBy> <hasName> Truc </hasName> <activityName> Eating Lunch </activityName> <id> 987 </id> <time> 14:05:00 </time> </activity>	<activity type="Video"> <detectedBy> Video Sensor </detectedBy> <hasName> Truc </hasName> <activityName> Increased Calories </activityName> <id> 1012 </id> <time> 14:15:00 </time> </activity>

This information is converted into the designed ontological format, fused and later logged in Life Log repository. Table 2 shows the converted and fused N3 notations of the received context.

Table 2. N3 representation of the fused context information

kb:ActivityInstance_145892 a: kb:Activity; kb:hasId: kb:666; kb:hasName: kb:In Restaurant; kb:hasConnectedActivity: kb:null; kb:resultedIn: kb:null; kb:hasAction: kb:null; kn:hasSensorType: kb:Location Sensor; kb:lostFor: kb:DurationInstance_3452612; kb:performedBy: kb:ActorInstance_345; kb:atLocation: kb:LocationInstance_245; kb:dependsOn: kb:null;	kb:ActivityInstance_145894 a: kb:Activity; kb:hasId: kb:987; kb:hasName: kb:Eating Lunch; kb:hasConnectedActivity: kb:ActivityInstance_145892; kb:resultedIn: kb:null; kb:hasAction: kb:null; kn:hasSensorType: kb:Body Sensor; kb:lostFor: kb:DurationInstance_3452634; kb:performedBy: kb:ActorInstance_345; kb:atLocation: kb:LocationInstance_245; kb:dependsOn: kb:null;	kb:ActivityInstance_145945 a: kb:Activity; kb:hasId: kb:1012; kb:hasName: kb:Increased Calories; kb:hasConnectedActivity: kb:ActivityInstance_145892, kb:ActivityInstance_145894; kb:resultedIn: kb:null; kb:hasAction: kb:RecommendationInstance_231; kn:hasSensorType: kb:Video Sensor; kb:lostFor: kb:DurationInstance_3452762; kb:performedBy: kb:ActorInstance_345; kb:atLocation: kb:LocationInstance_293; kb:dependsOn: kb:ActivityInstance_145892;

While fusing this context information with the profile information of the respective patient, the proposed system has proved its worth here by reporting that the current patient is a heart patient and the happenings of high calories and fats intake is not good for patient's health. The proposed system has encountered a negative situation about patient and the system is checking the history of the problem (associated to patient) to make appropriate analysis. Our proposed system has extracted Life Log information of the respective patient using the abstract sparql query given in Fig 3 and has performed behavior analysis to see whether such situations occurred before or not.

```
SELECT ?activity ?performedBy ?time  ?topic ?hasConnectedActivities ?dependsOn ?Location ?Diet, ?interaction, ?Action
    WHERE { Lifelog:Activity :hasName  ?activityName .
      ……
    Lifelog:Activity  :hasPerformedBy ?performedBy .
    Lifelog:Activity  :hasConnectedActivity ?hasConnectedActivities .
    Lifelog:Action :hasAction ?Action .  }
```

Fig. 3. Sparql query for extraction of fused context from Life Log

The analysis report has stated that such situation has occurred before, and mostly it has happened after taking food at restaurants. The system generates alert for the patient about the adverse situation which may persist if patient maintains the same behavior in food selection. Finally, the system recommends him to go for a walk or any other prescribed routine to burn some calories. Fig 4 shows component diagram of the execution flow for behavior analysis and prediction services.

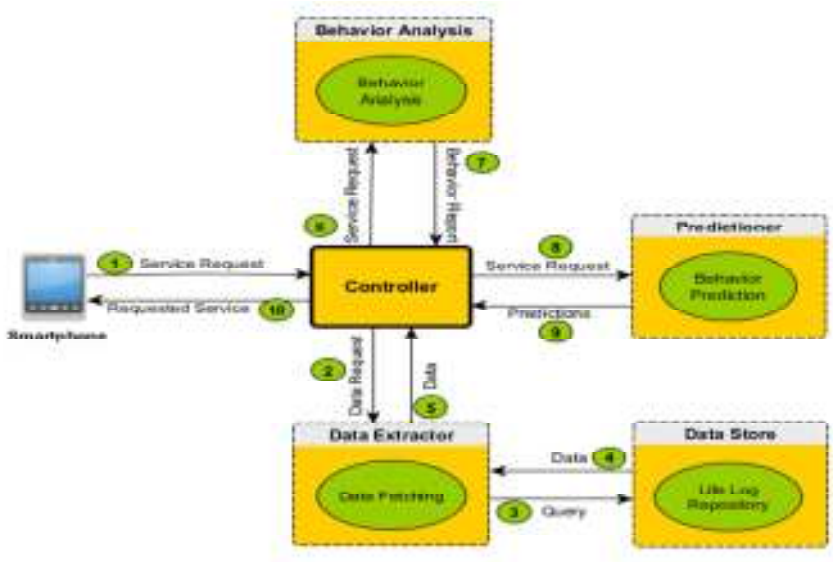

Fig. 4. The diagram showing execution flow for the behavior analysis and prediction services of proposed system

It is visible from Fig 4 that for the services of behavior analysis and prediction, the context information from Life Log is extracted which is then used in inference engines at behavior analysis and prediction module to generate appropriate services. The results of services are provided to patients on their smartphones as well as in audio reminders format.

5 Conclusion

Healthcare and behavioral services are important to analyze daily behavior and have better lifestyle. To facilitate the aspect of behavior analysis we have proposed a system that facilitates patients in provision of better lifestyle services, and behavior analysis and prediction. The system has used unified context representation related to the daily routine of a patient emerging from various sources of diverse nature. Context fusion techniques are developed to fuse related context which is then used for the analysis of the patient's behavior and for prediction of patient's behavior next state. The system is currently under development and will be deployed on cloud server to facilitate ease of access and low cost.

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