A Framework for Opportunistic Activity and Context Recognition

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Abstract. Opportunistic activity and context recognition systems draw from the characteristic to use sensing devices that just happen to be available rather than pre-defining a fixed sensor infrastructure at design time. Opportunistic sensing offers the possibility to obtain data from sensors that just happen to be available in the area surrounding the user. This enables users or applications to state recognition goals, saying what has to be sensed for, at runtime to the system. The available sensing devices that can contribute to the recognition goal are configured to an ensemble, which is the best set of sensors to recognize the goal. This paper describes the *OPPORTUNITY Framework* and shows its functionality with respect to four application cases (goal querying and sensor configuration, sensor appears/disappears, sensor learns from other sensor and sensor self trust) to show the dynamic nature of an opportunistic system as the available sensing infrastructure is not fixed and changes during runtime.

1 Introduction

Activity and context recognition in pervasive computing applications interpret environmental data acquired by sensing devices in terms of inferring activities and more generally the context of persons and subjects in real world environments. One common problem of all activity and context recognition systems so far is that the sensor deployment is application specific and thus the mapping from the sensor signals to the context and activities has to be known at *design time*. The concept of opportunistic activity and context recognition systems draws from the characteristic to use sensing devices that just happen to be available [5]. Users and/or applications can state recognition goals at runtime to

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the system. The currently available sensing devices that can contribute to the goal are configured to an ensemble which is the most appropriate set of sensors to deliver data to recognize the goal.

Different sensor systems that can be roughly classified in the groups physical, logical or virtual, have different working characteristics, measure different environmental quantities and deliver different types of data (acceleration, orientation,...) and they might be accessible and controllable in different ways. Therefore, to have a simple and standardized access to different sensing devices, wrappers are needed, which encapsulate hardware details and hide the low level access to the sensing devices. These wrappers referred to as *sensor abstractions* are software abstractions of the sensing devices that provide the complete functionality to a system by hiding its complexity and provide reusable building blocks for all systems [1].

An essential requirement to build sensing ensembles is to quantify how good a single sensor or an ensemble can contribute to a recognition goal. The approach presented in [3] describes two metrics namely the *degree of fulfillment - DoF* and the *Trust indicator (TI)*, both values between [0,1]. The *DoF* indicates to which extent a single sensor or sensor ensemble can contribute to a given goal. It is a static value that is calculated during the training phase of the sensors by considering the recognition rate, the confidence, the precision and the accuracy which can be extracted by comparing the predicted class against ground truth. The *TI* indicates how trustworthy the delivered data from a sensor is. This value can change during runtime due to data loss, faulty data, rotation or movement of the sensor.

2 OPPORTUNITY Framework

2.1 Goal Querying and Sensor Configuration

When a recognition goal is stated to the *OPPORTUNITY Framework*, the available sensors are queried by the system to get knowledge about which sensors can contribute to the given recognition goal. Each sensor that can contribute to the recognition goal, as stored in the *self-description* of each sensor, responds to this *"I need request"* in how good it can contribute to the given goal with respect to the *DoF* and the *TI*. The responds are analyzed with respect to the *DoF* and the *TI* and an ensemble, the best set of available sensors, with the highest *DoF* according to the stated recognition goal, is structured and configured.

2.2 Sensor Appearing/Disappearing and Ensemble Configuration

If a sensor appears, it is queried to get its capabilities. After the response of the sensor, the *OPPORTUNITY Framework* knows to which goals and to which extent the sensor can contribute to. If the newly detected sensor can contribute to the actual recognition goal, the framework analysis if the use of this sensor would improve the recognition of the actual goal (*DoF*). If this is the case the ensemble is restructured and the sensor is integrated into the ensemble to get the best recognition rate. Detecting the disappearance of a sensor, the *OPPORTUNITY Framework* reacts in reconfiguring the ensemble. A querying of the still available sensors is not necessary as this sensors have already been queried before and the stored information is used to select the sensors accordingly.

2.3 Transfer of Recognition Capabilities

In an open-ended environment, new sensors may be discovered during runtime that might not have been trained yet to fulfill a given recognition goal. Therefore the *OPPORTUNITY Framework* is capable of transferring recognition capabilities from one sensor to another [2]. If the *OPPORTUNITY Framework* detects the appearance of a sensor, it queries this sensor. During the querying process it is decided dependent on the stored information in the *self-description* of the sensor, if this sensor is a candidate to be learned with the actual recognition goal. If the sensor is chosen as a learning candidate for the actual recognition goal, the *OPPORTUNITY Framework* reacts with connecting it to the actual sensing mission and trains this sensor, respectively its *recognition chain* (consisting of feature extraction and classifier) using transfer learning with the labels/classes that are produced by the current sensing ensemble. During the training process, the *DoF* of the trained sensor is dynamically calculated and adapted according to the comparison of the output of the teacher and the learner that is done periodically after a certain amount of time to get a reliable value for the *DoF* of the learner. After the learning process is finished, the trained sensor can be used to detect the goal, respectively the labels, it was online trained for during runtime.

2.4 Sensor Self Trust and Ensemble Reconfiguration

According to the recognition goal, the *OPPORTUNITY Framework* selects the best sensor ensemble. As sensors can deliver faulty data due to packet loss during the physical transmission of the data or on a change in position, rotation or malfunctioning of the sensor itself, each sensor is aware of how plausible the data it delivers is. This reliability measurement called *Trust Indicator* indicates the self-awareness capabilities of the sensor, thus describing the plausibility of the delivered data from the sensor as a value between [0,1]. Changes in the *TI* value influence the *DoF* as when the quality of the delivered data changes, also the DoF changes. As the *DoF* is a fixed value that is generated during the learning process of the sensor/classifier using performance measurements (e.g. insertions, deletions, confusion matrix, . . .) it is therefore multiplied by the *TI* to get the overall QoS indicator [3]. As the *TI* value changes during runtime of the system, the *OPPORTUNITY Framework* has to monitor the *TI* of each sensor and react on changes. Reacting means, that if the *TI* falls e.g. beneath a certain threshold, the sensor might not be useful for the ensemble any more and thus a reconfiguration of the ensemble is necessary. The *OPPORTUNITY Framework* is capable of detecting faulty sensors using anomaly detection [3] and to do a reconfiguration of the ensemble if the *TI* of a sensor indicates a change in the plausibility of its delivered data, to ensure to have the best ensemble configured.

3 Conclusion

We introduced the concept of opportunistic sensing, that draws from the characteristic to use sensing devices that just happen to be available rather than being dependent on a pre-defined sensing infrastructure. We presented the dynamic behaviour of such a system using the *OPPORTUNITY Framework*, a reference implementation of an opportunistic system, demonstrating the dynamic configuration of sensor ensembles according to recognition goals and its behaviour on changes in the sensor infrastructure as tested on a large scale dataset [4] collected to exhibit the sensor-rich characteristics of opportunistic sensing systems.

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