Adaptive Personalisation of the Intelligent Space by Fuzzy Automaton

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Abstract: Application of fuzzy automaton in Intelligent Space gives a simple way for quick adaptive personalisation. The concept of 'Intelligent Space' was originally introduced in 1996 by the Hashimoto Laboratory at the University of Tokyo, as a mixed human-robot assisted environment, where the robots are controlled by the the distributed intelligent devices of the 'Intelligent Space' called Ubiquitous Sensory Intelligence which is realized by Distributed Intelligent Networked Devices (DIND) [3]. As a high level, context sensitive interface to robots, the Intelligent Space has the task to adapt the expected human requirements by identification of the actual human behaviour, by 'personalisation' of the Intelligent Space. This 'personalisation', as an adaptive personal model estimation, can be done by identification of the actual personal model in the space of the existing personal models based on the actual personal features observed by the Intelligent Space. This paper suggests the adaptation of fuzzy automaton for quick and simple personalisation and the adaptive fusion of the existing personal models for estimating the actual personal model.

Keywords: intelligent space, fuzzy automaton, user adaptivity, personalisation

1 Introduction

As a high level, context sensitive interface to robots, the Intelligent Space has the task to suit the demands of the actual user. On the other hand, user demands can be strongly dependant on the actual task, behaviour or habit of the human operator. Moreover in case of appearing a new user, the Intelligent Space should identify, or approximate the actual user demands, based on the observed actual personal features, in a relatively short time. From the viewpoint of the Intelligent Space, this demand, or behaviour identification can be seen as a 'personalisation' of the unknown user. The 'personality' of the actual user serves as an actual user model, the relation of the personal features observed by the Intelligent Space and the expected user demands (summarised in the personal behaviour). To keep the identification process quick, it must be based only on a relatively few feature observations. On the other hand, to build up a user model characterising more personal features needs numerous feature observations. One way of solving this contradiction is the application of known existing user models. This case the identification process has the goal of identifying (or locating) the actual user in the space of existing user models only, not the identification of the complex user model itself.

As a main contribution, this paper suggests the adaptation of fuzzy automaton for quick and simple user personalisation and the adaptive fusion of the existing user models for estimating the actual personal model. In the following sections, first the concept of Intelligent Space, then a way for actual user personalisation based on existing user models and the adaptation of fuzzy automaton will be introduced.

2 The Intelligent Space

The concept of 'Intelligent Space' was originally introduced in 1996 by the Hashimoto Laboratory at the University of Tokyo, as a mixed human-robot assisted environment, where the robots are controlled by the distributed intelligent devices of the 'Intelligent Space' [1], [2], [3]. Mobile robots were located in the Intelligent Space for supporting people as well as for being supported. Vision cameras and computers sets were arranged around an entire room, changing it into an Intelligent Space. Conventionally, there is a trend to increase the intelligence of a robot operating in a limited area. The Intelligent Space concept is the opposite of this trend. The surrounding space has sensors and intelligence instead of the robot. A robot without any sensor or own intelligence can operate in an Intelligent Space. In the conventional solution the robot measures, calculates and decides. The heart of the Intelligent Space concept is that the robots must not measure, calculate or make decision. They just carry out and execute commands getting information from the distributed devices called Ubiquitous Sensory Intelligence. The

Ubiquitous Sensory Intelligence is realised by Distributed Intelligent Networked Devices (DIND) [1], [2], [3] and robots, which are the physical agents of the Intelligent Space. In the Intelligent Space, DINDs monitor the space, and achieved data are shared through the network, since robots in the Intelligent Space are equipped with wireless network devices, and hence DINDs and robots can organize a network. The Intelligent Space consists of humans too, not only sensors cameras or robots. The Intelligent Space based on Ubiquitous Sensory Intelligence supply information to the Human beings and it can help them physically by using robot agents. A figure of the Intelligent Space concept with ubiquitous sensory intelligence is shown on Fig. 1. The conceptual difference of the conventional and Intelligent Space is introduced on Fig. 2.

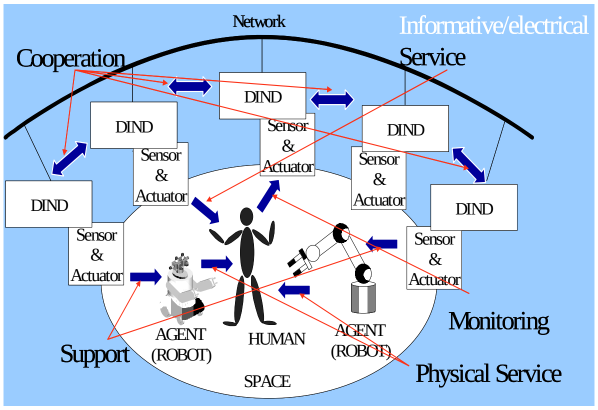
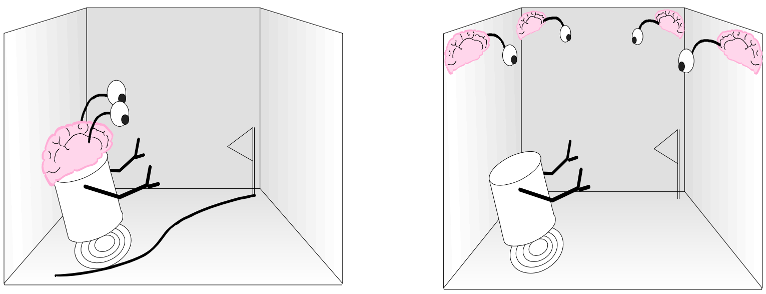


Figure 1
The Intelligent Space Concept



Conventional concept | Ubiquitous Sensory Intelligence concept

Figure 2
Conventional and Ubiquitous Sensory Intelligence concept

The Intelligent Space is a human supporting system. Events have to be understood and the space can support human in need even physically, by its robots which can handle real objects too. Mobile robots become physical agents of the Intelligent Space, hence they execute tasks in the physical domain to support people in the space. Tasks are extended to moving objects, providing help to aged or disabled persons, guiding blind, etc. Thus, the Intelligent Space is an environmental system, which supports human not only by information, but physically too, as it can serve as a high level, context sensitive interface to robots.

The Intelligent Space tries to identify the behaviour of the human beings and tries to predict their demands in the near future. Using this knowledge, the intelligent space can unnoticed help humans. A mobile robot with extended functions can be introduced as a mobile, Intelligent Space assisted haptic interface. Hence the mobile haptic interface can e.g. guide and protect a blind person in a crowded environment. This case the Intelligent Space learns the obstacle avoidance method (walking habit) of other dynamic objects (human beings) by tracing their movements and helps to the blind person to avoid the collision and the blind person can communicate (sends and receives commands) by the tactile sensor.

3 Adaptive Personalisation by Fuzzy Automaton

As a high level, context sensitive interface to robots, the Intelligent Space has the task to adapt the expected human requirements by identification of the actual human behaviour, by 'personalisation' of the Intelligent Space. This 'personalisation', as an adaptive personal model estimation, can be done by identification of the actual personal model in the space of the existing personal models based on the actual personal features observed by the Intelligent Space. This paper suggests the adaptation of fuzzy automaton for quick and simple personalisation and the adaptive fusion of the existing personal models for estimating the actual personal model.

One of the difficulties of building personal model, the relation of the observed personal features and the actual personal behaviour, in the Intelligent Space in case of the appearance of a new user, is the insufficient number of feature observations. A possible solution of this problem is the abandoning of the adaptivity and the application a fixed universal personal model serving the demands of a single personal behaviour. This personal model can be generated off-line, based on a wide user inquiry, or as a statistical average of long time observation of the personal features and the related personal demands [4], [5]. In case of the demand of adaptive personalisation the single personal model concept can be also extended by introducing learning methods to modify a global personal model based on the actual personal feature observations [6], [7], [8]. On the other hand having a single global personal model adapted by relatively few and specific observations can lead to incoherence (in sense of the consistency, or locality of the modification) of the personal model.

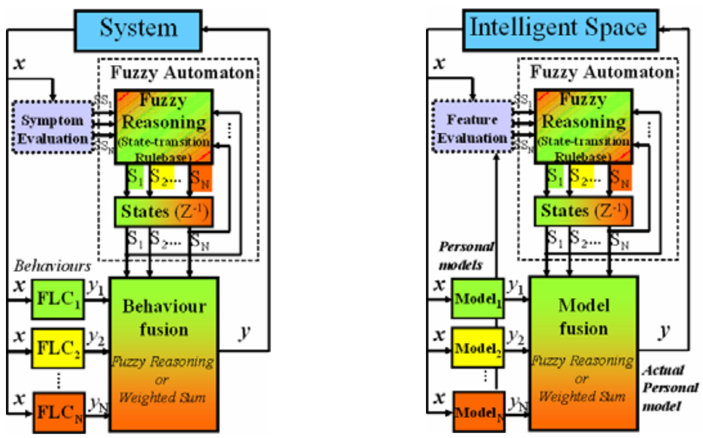
Fighting the problem of the probable occasional incoherence, and to give a simple way for implementing model adaptivity, this paper suggests the adaptation of behaviour-based strategy fusion (in this case personal model fusion) techniques for adaptive personalisation. The main benefit of the proposed behaviour-based structure, that it achieves user adaptivity by fusing some existing fixed (off-line collected) personal models. This fusion is done globally in the manner of 'more similar the actually observed personal feature to one of the existing personal models, more similar must be the actual personal model to that personal model'. Supposing, that all the off-line collected personal models are appropriate, and that the fusion (combination) is affecting coherently the entire personal model, hopefully the personal model incoherences can be avoided (i.e. in case if the convex combinations of the valid personal models are also lead to valid personal models).

Another difficulty of building a personal model, is the highly model dependent interpretation of the observed personal features. In most cases the same observed personal feature can belong to more different personal models. To give a chance for distinguishing these personal models, in this paper the concept of 'identification state', as a preconception, is introduced. Hence a rule based system can also speeding up the identification process (see more detailed in the explanation of rule base (1)), this paper suggests the adaptation of fuzzy automaton for quick and simple personalisation and the adaptive fusion of the existing personal models for estimating the actual personal model. (This technology is already successfully applied in introducing quick personalisation (user adaptivity) for Kansei technology [12], [13].)

3.1 Behaviour-based Control Structure for Personalisation

In behaviour-based control systems (a good overview can be found in [9]), the actual behaviour of the system is formed as one of the existing system behaviours (which fits best the actual situation), or a kind of fusion of the known behaviours appeared to be the most appropriate to handle the actual situation. A different view of the same problem is a kind of situation adaptive strategy reconfiguration. The main idea of this view is the following: 'The more similar the actual situation to the prerequisites of one of the known strategies, the more similar the strategy used to that strategy must be'. Considering the actual user to be the actual situation and the existing personal models to be the different strategies, it is very easy to adapt the behaviour-based control system structure for adaptive personalisation in the Intelligent Space. Having more personal models, personalisation can be simply achieved by fusing them in the function of their approximated suitability for the actual user.

The application of behaviour-based control has two main tasks. The first is a decision about the levels of necessities of the different strategies (personal models in this case); the second is the way of the strategy (personal model) fusion. The first task can be viewed as an actual system state approximation, where the actual system state is the approximated level of similarities of the actual situation (user in this case) to the prerequisites of all the known strategies (to the existing personal models). The second is the fusion of the existing strategies (personal models) in the function of the corresponding similarities. For the first task, in this paper the adaptation of fuzzy automaton is suggested (where the state variables are the corresponding similarities, and the state-transitions are driven by fuzzy reasoning (State-Transition Rulebase on Fig. 3)). For the second task, the convex combination of the existing personal models in the function of the corresponding similarities approximated by the fuzzy automaton is suggested.



Behaviour-based Control　　　　Adaptive personalisation

Figure 3
The suggested structure

3.2 Actual State Approximation by Fuzzy Automaton

For the actual system state approximation in this paper the adaptation of the fuzzy automaton is suggested. Its actual state (actual similarities, on Fig. 4) is a set of similarity values, the actual approximated similarities of the actual user to the existing personal models. In this concept, by approximating the state value, the user identification process has the goal of identifying (or locating) the actual user in the space of existing user models, instead of identifying directly the more complex model space. The state-transitions of the fuzzy automaton are driven by fuzzy reasoning (Fuzzy State Transition Rulebase on Fig. 4) as a decision based on the previous actual state (S_i, Actual Similarities on Fig. 4) and the similarities of an observed feature and the corresponding feature (SS_i, Actual Feature on Fig. 4) of all existing personal model in the model database ($\forall i \in [1, N]$, Fig. 4). Based on the actual similarities (SS_i) and the previous state (S_i), the new actual state (S_i) is calculated by the State-transitions Rulebase (1) (Fig. 4).

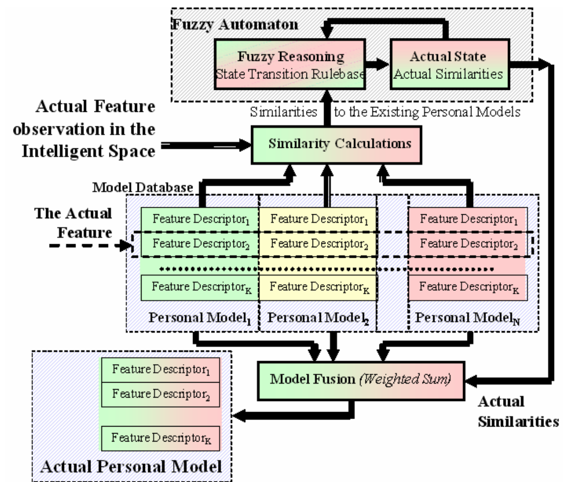


Figure 4

The proposed adaptive personalisation structure

The suggested heuristic for the state-transition rule base is very simple. If a suitable model (S_i) already found, and the user feedback (observed Actual Feature on Fig. 4) is still supporting it (SS_i), it needs to be kept, even if the user feedback began to support some other models too. If there were no suitable model, but the user feedback began to support one, it has to be 'picked up' at once, to support the quick convergence. In case of fuzzy rule interpolation [10], [11], the above heuristic can be simply implemented by the following state-transition fuzzy rule base [12], [13]. For the ith state variable S_i, $i \in [1, N]$ of the state vector **S**:

If S_i=One **And** SS_i=One **Then** S_i=One (1.1)

If S_i=Zero **And** SS_i=Zero **Then** S_i=Zero (1.2)

If S_i=One **And** SS_i=Zero **And** SS_k=Zero **Then** S_i=One $\forall k \in [1, N], k \neq i$ (1.3)

If S_i=Zero **And** SS_i=One **And** S_k=Zero **And** SS_k=Zero **Then** S_i=One $\forall k \in [1, N], k \neq i$ (1.4)

If S_i=Zero **And** SS_i=One **And** S_k=One **And** SS_k=One **Then** S_i=Zero $\exists k \in [1, N], k \neq i$ (1.5) where SS_i is the similarity of the observed feature to the corresponding feature of the i^{th} existing personal model $\forall i \in [1, N]$; N is the number of known personal models (state variables). The structure of the state-transition rules is similar for all the state variables. Zero and One are linguistic labels of fuzzy sets (linguistic terms) representing high and low similarity. The interpretations of the Zero and One fuzzy sets can be different in each S_i, SS_i universes.

Please note, that rule base (1) is sparse. It contains the main rules for the following straightforward goals only: Rule (1.1) simply keeps the previously chosen state values in the case if the symptom evaluation also agrees. The rule (1.2) has the opposite meaning, if the state values were not chosen, and moreover the symptom evaluation is also disagrees the state value should be suppressed. The rule (1.3) keeps the already selected state values (previous approximation), even if the symptom evaluation disagrees, if it has no better 'idea'. Rules (1.4) and (1.5) have the task of ensuring the relatively quick convergence of the system to the sometimes unstable (changeable) situations, as new state variables which seem to be fit, can be chosen in one step, if there is no previously chosen state, which is still accepted by the symptom evaluation (1.4). (Rule (1.5) has the task to suppress this selection in the case if exists a still acceptable state which has already chosen.) The goal of this heuristic is to gain a relatively quick convergence for the system to fit the demands of the actual user, if there is no state value high enough to be previously accepted. This quick convergence could be very important as the user feed-back information (feature observations) needed for the state changes are very limited.

For the complexity reduction benefits of the fuzzy rule interpolation (FRI) in case of the proposed rule base (1), as an example, see more detailed in [14] and [15].

Some state changes of the state-transition control (fuzzy automaton) in the function of the user feedback (SS_1, SS_2) for the two states case (applying the state-transition rule base (1)) are visualised on Figs. 5 and 6.

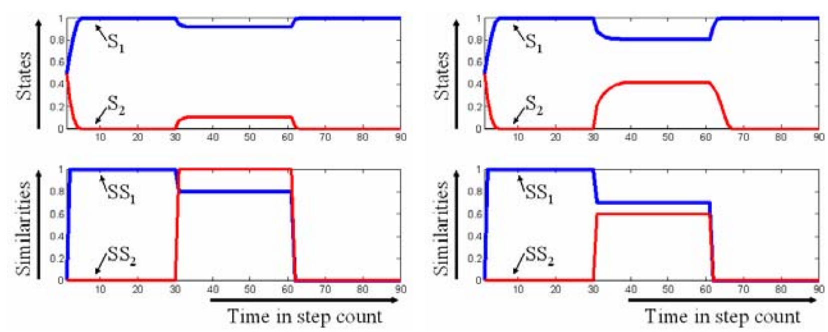


Figure 5
Do not 'pick up' a new state if the previous approximation is still adequate

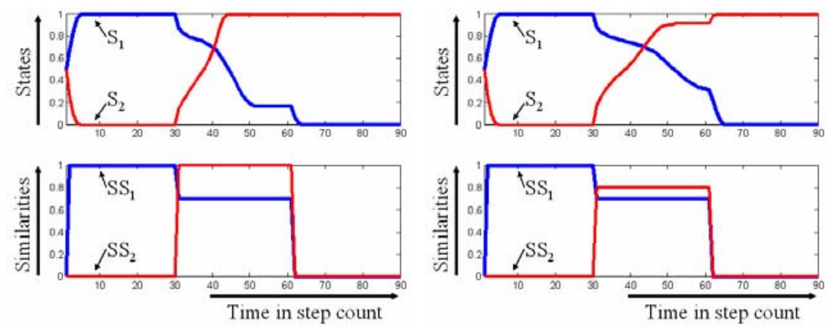


Figure 6
But 'pick it up' if it seems better

For checking the user feature approximating ability of the proposed adaptive personalisation structure in a continuously changing situation, a test personal model set, containing four personal models, each containing a single constant value feature [-0.9, -0.3, 0.3, 0.9], were set up. Running the actual user feature observations through the universe [-1,1], as a step function (repeating the same requirements 10 times, than jump), the actual (approximated) personal model feature value were able to follow the continuously changing observed features in the way as it is introduced on Fig. 6.

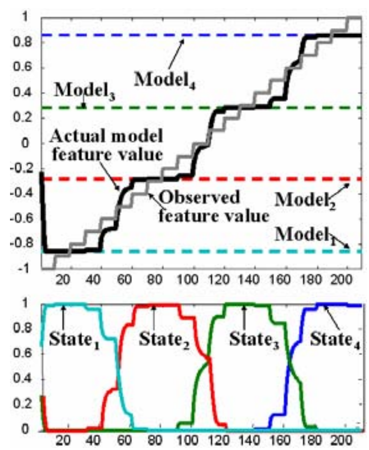


Figure 6
Test personal model set, step feature observations

Conclusions

As a high level, context sensitive interface to robots, the Intelligent Space has the task to suit the demands of the actual user. On the other hand, user demands can be strongly dependant on the actual task, behaviour or habit of the human operator. Moreover in case of appearing a new user, the Intelligent Space should identify, or approximate the actual user demands (building an actual personal model, as 'personalisation'), based on the observed actual personal features, in a relatively short time. For solving the problem of highly model dependent interpretation of the observed personal features and the speed requirement of personalisation, this paper suggests the adaptation of fuzzy automaton for quick and simple personalisation and the adaptive fusion of the existing personal models for estimating the actual personal model.

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