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A learning system for adjustment processes based on human sensory perceptions

Francisco Javier Ruiz [a,c], Núria Agell [b,c,*], Cecilio Angulo [a,c], Mónica Sánchez [a,c]

[a] UPC BarcelonaTech, Barcelona, Spain
[b] ESADE, Universitat Ramon Llull, Barcelona, Spain
[c] Knowledge Engineering Research Group, Barcelona, Spain

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Abstract

Creating, designing and adjusting products are essential decision processes underlying creative industries, such as painting, perfume, food and beverage industries. These processes require the participation and continuous supervision of professionals with highly-developed expert sensory abilities. Training of these experts is very complex due to the difficulty of transmitting intuitive knowledge obtained from perception. A new methodology for capturing this sensory expert knowledge that relies on a machine learning tool, previously trained with 'state-action' type patterns, jointly with an actions generator module, is proposed in this work. The method is based on a closed loop architecture together with the decomposition of complex sensory knowledge into basic elements capable of being handled by standard machine learning systems. A real case application to color-adjustment in the automotive paint manufacturing industry is presented showing the potential benefits of the method.

Keywords: Artificial cognitive systems; Expert knowledge management; Color adjustment; Color formulation

1. Introduction

Industries with specialized professionals that use their sensory abilities for designing, formulating and tuning their products, are faced with huge challenges when managing and disseminating these skills (Seaborn, Hepplewhite, & Stonham, 2005; Wright, 2010). In particular, perfume, food, beverage, painting, and other creative industries continuously deal with problems in modeling processes based on the cognitive ability of these highly specialized individuals (Allais, Perrot, Curta, & Trystram, 2007; Banerjee et al., 2012).

Creative processes are not purely functional or physical, but arise from highly subjective perceptive and cognitive aspects which cannot be completely modeled by standard quantitative structures. In these tasks, the intervention of human experts, including colorists, perfumers, chefs, sommeliers, or brew masters, becomes necessary, preventing the complete process automation. Two different design tasks involving these highly specialized human experts can mainly be distinguished: the *formulation task* and the *adjustment or tuning task*. On the one hand, the formulation task concerns the process of finding an appropriate set of ingredients and their proportions, and how to combine them in order to get a target product. Once the formulation task is completed, the product is ready to be manufactured in the production phase.

On the other hand, the adjustment or fine-tuning task is performed during manufacturing (Bondioli, Manfredini, &

* Corresponding author at: ESADE, Universitat Ramon Llull, Barcelona, Spain.

E-mail addresses: francisco.javier.ruiz@upc.edu (F.J. Ruiz), nuria.agell@esade.edu (N. Agell), cecilio.angulo@upc.edu (C. Angulo), monica.sanchez@upc.edu (M. Sánchez).

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Romagnoli, 2006; Herrera et al., 2010). This task must be performed whenever the product is nearly finished and has to be corrected in order to achieve the target product with the desired precision and quality. In the adjustment process, the expert, based on his/her sensory experience and abilities, determines slight variations in the proportions of one or more ingredients or variations in the combination processes. The expert intuition usually does not allow him/her to know the exact quantities to increase to achieve the goal or target. However, he/she is able to iteratively determine the approximate quantities to add or actions to perform in a closed loop control process until the final target is met. Adjustment tasks require a lot of highly qualified human and time resources. Costs associated to this kind of tasks are economically considered quality non-conformance costs, i.e. costs derived from fixing failures to accomplish specific requirements. They are usually expensive and affect the firm's profit margin and its competitiveness.

This paper introduces an innovative artificial cognitive system to support decision-making in adjustment processes based on human sensory abilities. The proposed system, based on expert knowledge management, draws on a machine learning tool jointly with an actions generator module. A Support Vector Machine (SVM) (Boser, Guyon, & Vapnik, 1992) is previously trained with 'state-action' type patterns provided by experts. Then, it enables the identification and selection of the most adequate action among those provided by the generator module for a particular state. The coupled actions generation-selection process is iterated until the final state satisfies certain conditions, i.e. until the target is achieved. The main contributions of the methodology proposed are twofold. Firstly, it proposes how to decompose complex sensory knowledge into basic elements capable of being handled by standard machine learning systems. Secondly, it follows expert behavior performing an adjustment process within a closed loop architecture.

The proposed system aims to reduce non-conformance costs when employed in a software tool. In addition, it will reinforce quality assurance efforts since the customer will permanently receive conforming products. The methodology presented has been developed and tested for color adjustment in basecoat painting. However, it can be extended to other similar tuning processes in highly creative industries, where specialized professionals with sensory abilities are implied.

The remainder of this paper is organized as follows. In Section 2, the presentation of the adjustment task in sensory products manufacturing is presented. Both, the concept is outlined and the methodology is formalized. A brief introduction of the color adjustment problem together with a real-case application for automotive basecoat manufacturing is presented in Section 3, showing that the new method is a suitable tool for this purpose. Section 4 describes the experimentation performed in a real-case application that compares expert knowledge to simple metric properties of the colorimetric space. Finally, Section 5 highlights some conclusions and future tasks related to the research line followed in this work.

2. A learning system for automated adjustment processes

Our proposal considers the process of adjustment as a Deterministic Markov Decision Process (DMDP) composed mainly by a set of states, a set of actions and an immediate reward function that quantifies the benefit of choosing one or another action. In a DMDP, a policy is a function that specifies the action chosen in each state. The core problem of DMDP is to find an optimum policy, which is the policy that maximizes some cumulative function of rewards. Reinforcement Learning is a common paradigm to deal with DMDP. It comes into play when examples of desired behavior are not available and it is based on the trade-off between *exploration*, or discovery of new actions, and *exploitation*, or preference for actions that have already been shown to be useful. Our proposal, in contrast to a Reinforcement Learning paradigm, takes advantage of expert knowledge by reducing the cost of exploration part using a standard supervised machine learning to induce the policy by querying the expert.

The proposed learning method is based on capturing and representing expert knowledge to relate product composition and its properties to generate specific sensations. Specifically, the main objective is to capture experts' skills during the adjustment process to later be able to use this knowledge in a decision support system. Information will be obtained from both, the appropriate representations (characterization of product features, such as existing nomenclature and metaphorical categories, available ingredients and control parameters) and mappings (suitable transformations to achieve the target). Next, machine learning techniques will be applied to replicate the problem-solving ability found in adjustment processes, in which individuals deploy their highly trained senses.

2.1. Problem representation

Let $(\mathcal{S}, d)$ be the metric space of the set of states $\mathcal{S}$ in an adjustment process, together with a distance d. For each state $s_i \in \mathcal{S}$, a set of possible actions $\mathcal{A}_i$ (either, finite or not) is associated. Similarly to a state machine, when an action $a \in \mathcal{A}_i$ is carried out, a transition takes place and the system moves from the state s_i to the state s_j. For deterministic state machines, it is verified that the subsequent state is a function of the current state s_i and the performed action $a \in \mathcal{A}_i, s_j = F(s_i, a)$. The distance function and the target state allows us to define a complete preorder relation in the set $\mathcal{S}$.

Definition 1. Given the metric space $(\mathcal{S}, d)$ of the set of feasible states in an adjustment process, together with a distance d, the relation *to be more favorable than*, denoted by $\succcurlyeq$, is defined as: