Personalized Clothing-Recommendation System based on a Modified Bayesian Network

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***Abstract*—This paper presents a clothing-recommendation system that suggests personal combinations from a user's wardrobe. Online shopping websites use recommendation systems to suggest items that users might be interested in. Such systems make recommendations to a user on the basis of other users' behavior, under the assumption that all users behave similarly; personal preferences are not captured. However, a clothing-recommendation system should make recommendations on selections of personal items based on personal preferences rather than other users' behavior, since it is rare to find other users that own the same articles of clothing as the target user. The proposed system makes recommendations that are particularly suitable to a user based on the user's personal preference, history of clothing items and the user's evaluations of previous system recommendations. The experimental results reveal that the system can in most cases recommend more suitable combinations of clothing items than can existing systems under the same conditions.**

Keywords-component: recommendation system; personalized clothing; Bayesian network

I. Introduction

Recommendation systems are widely used to suggest music, films, books, and other products to users of online shopping sites. Online stores like Amazon suggest items that a user might want to purchase based on similar users' behaviors. Such recommendation systems suggest new items without capturing actual personal preferences, and avoid repeatedly showing the same items that have been recommended. On the other hand, owned-items recommendation systems recommend the same items, such as recipes or clothing, in suitable combinations.

Radio Frequency Identification (RFID) technology [1] is widely used for supply chain management and inventory control. The world's largest retailer, Walmart, has been using RFID tags on clothing since 2010. The typical architecture of RFID applications [2] consists of these tags, which are embedded in or attached to an object, and an RFID reader and IS (information services) server. The tag is attached to or integrated with an object such as an article of clothing so that the tag can be read by the RFID reader to identify information about the article (such as color, texture, or sleeve length).

Most existing recommendation systems use collaborative filtering [3], which makes recommendations about the preferences of a user on the basis of other users' collective taste information. By contrast, content-based filtering [4], uses information about the item itself to make suggestions. However, such recommendation systems perform unsatisfactorily without large amounts of usage data or knowledge information.

A Bayesian network [5] is a flexible method for modeling complex joint probability. The high flexibility of a Bayesian network is appropriate for representing the complex relations between user preference and context. Morimoto et al. [6] proposed a system based on the Bayesian model that uses clothing parameters and can recommend clothing depending on the date and amount or type of clothing that the user wants to wear. In the system, the contextual-knowledge nodes in the Bayesian network include properties of the clothing and current weather. However, the Bayesian network does not have a mechanism to reflect users information, such as their preferred items or combinations and their clothing history, in the recommendations of the system.

This paper proposes a system to recommend clothing combinations from a user's wardrobe. The system consists of clothing information and coordination information. According to the current situation (i.e., the day's weather and the user's schedule), the system recommends an appropriate combination from the user's available clothing options. Moreover, the user's evaluation of the recommendation is used to modify the coordination information. In addition, the system assumes that the use of RFID technology is available to glean clothing information from an RFID tag.

The remainder of this paper is organized as follows: Section 2 presents our approach to developing a clothing-recommendation system. Section 3 explains the proposed system itself. Section 4 discusses the procedure used for the evaluation of the system and its results. Section 5 presents the conclusion and an outline of needed future work.

II. Proposal for a Personalized Recommendation System

In the proposed model, a recommendation system using a Bayesian network is developed for producing combinations of clothing from a user's wardrobe. Figure 1 describes the proposed clothing-recommendation system, which recommends combinations depending on the current situation (weather, user's schedule for the day, etc.). In order to recommend suitable combinations, the system is divided into two parts. The first part shows the decision-making process in

This research sponsored by JST/CREST/ULP research area
WS-6: The 3rd Workshop on Enablers for Ubiquitous Computing and Smart Services

selecting a top (shirt, blouse, sweater, etc.); the nodes for contextual knowledge can be related to clothing (e.g., sleeve length, color), situation (season, occasion, temperature), and a record of recently recommended clothing (to avoid recommending anything too frequently). The second part selects bottoms (pants, skirts, shorts, etc.), which should match the selected top. This process solicits feedback by the user, and the Bayesian network identifies clothing features (type, color), and situation (season, occasion). The coordination strategy is modified when the user is unsatisfied with a combination.

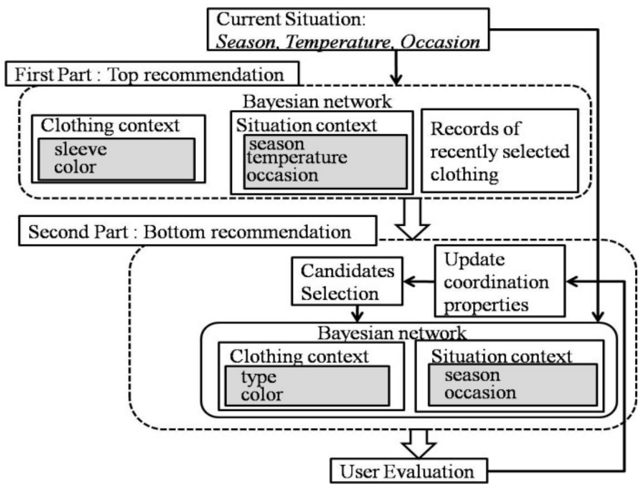

Figure 1. Proposed clothing-recommendation system

III. Method for Personalized Recommendation

In the present system, a personalized recommendation is made using Bayesian networks incorporating item usage history and user feedback when selecting a bottom to go with a top.

A. Bayesian Network with Probability Function Reflecting Item Usage History

A user owns clothing items according to her / his preference so that the number of clothing items will not be the same for each color. We assume it desirable for users that the system recommends items suitable to the specified temperature, season and occasion considering the records of clothing selection, and that every item is recommended with equal frequency. We construct the Bayesian network for the system by two steps so as to satisfy the above two requirements. An example of the Bayesian network topology for the first step is given in Figure 2.

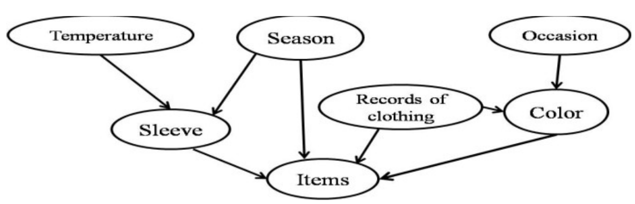

Figure 2.Structure of the basic Bayesian network

The sleeve type of a top is recommended by the probability function inputted with the parameters of temperature and season, and the color is recommended according to the probability function taking the specified occasion and the record of clothing selection into account. The system recommends every color by checking the record of clothing selection, where the rate of selection is not controlled to be equal for each item. We call such Bayesian networks without satisfying the second requirement by "basic Bayesian networks." The Bayesian network to satisfy both the first and the second conditions is designed by adding the new color node as in Figure 3. The probability function at the new color node to recommend items is given by Eq. (1),

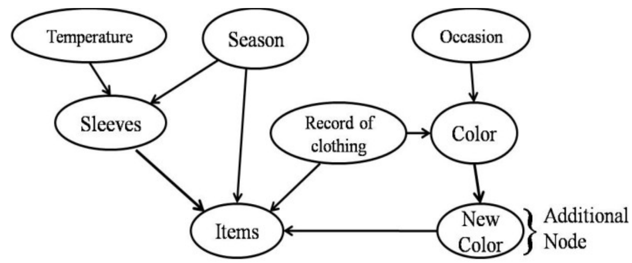

Figure 3. Structure of the extended network

$$P(c) = \frac{F(c) \times P\mathit{Bay}(c)}{\sum (F(c) \times P\mathit{Bay}(c))} , \qquad (1)$$

where $P\mathit{Bay}(c)$ is the probability function for the basic Bayesian network to select a color "c" and F(c) is defined by Eq. (2) and (3) using the number, N(c), of clothing items with color c and the number, T(c), of times color c has been recommended recently, but if $T(c) = N(c)$ ($\sum T(c) = \sum N(c)$) then T(c) restarts from 0.

$$\text{If } N(c) > 3 \qquad F(c)= \frac{N(c)- T(c)}{T(c)+1} \qquad (2)$$

$$\text{If } N(c) \leqq 3 \qquad F(c)= \frac{\sum N(c)- T(c)}{\sum T(c)+1} \qquad (3)$$

Function F(c) is defined differently according to the size of N(c) because we have found in the experiment that a color is not recommended by Eq. (2) without the condition in terms of N(c) if the number of clothing items with that color is less than three.

B. User feedback mechanism for bottom selection

A user may dislike the combination of red and pink, for example, but the Bayesian network system may still recommend a red blouse with a pink skirt. In order to have the system make an appropriate decision with regard to user preference, we propose a user feedback mechanism for bottom selection.

At the beginning of the second stage, the system searches the candidate bottoms whose properties match the current situation and the chosen top. A bottom is selected based on the user's clothing history and feedback, as discussed above. Thus, the system learns when the user is not satisfied with its recommendation. The properties of matching discussed above are the reference for top and bottom coordination.
The following C(P) takes a value of 1 or 0; the values 1 and 0 indicate and rule out, respectively, that bottom P can be a candidate for recommendation:

$$C(P) = Season(P) \times Occasion(P) \times Pattern(P) \times Color(P) \quad (4)$$

Here Season(P), Occasion(P), Pattern(P), and Color(P) represent the properties of bottom P, taking values of 1 or 0. A value of 1 determines that bottom P satisfies the properties these functions represent. Season(P) indicates whether season P (the season for which the article of clothing was designed) is the current season; Occasion(P) indicates whether occasion P is the occasion that the user is scheduled to participate in; Pattern(P) indicates whether bottom pattern P matches the selected top; Color(P) represents whether the color designed for P is in harmony with the color of the selected top, based on the properties of fashion coordination

Considering the following assumptions: season—spring; occasion—everyday; top pattern—none; and color—pink. An example of bottom search results is given in Table 1 and 2. Table 1 includes the properties given above; under them, C(P) is calculated in Table 2. For example, C("Pants1") = 1 × 1 × 1 × 1 = 1, as shown in Table 2. Consequently, Pants1 and Skirt1 are enumerated as candidate bottoms.

Table 1. Example of candidate bottom properties

Bottoms	Season	Occasion	Type	Color
Pants1	Spring	Usual	Simple	Pink
Pants2	Spring	Special	Simple	Yellow
Skirts1	Spring	Usual	Flower	White
Skirts2	Winter	Usual	Simple	Green

Table 2. C(P) of bottoms

Bottoms	Season	Occasion	Type	Color	Result
Pants1	1	1	1	1	1
Pants2	1	0	1	1	0
Skirts1	1	1	1	1	1
Skirts2	0	1	1	0	0

In the proposed system, the user can give an evaluation score for a recommended combination. The evaluation score ranges from 1 to 5 ("bad" to "good"). Figure 4 is a flow chart for system learning. When the evaluation score is less than or equal to 3 and the user can choose parameters (which include not only the ones given above but also others such as texture), if he or she thinks the combination can be improved, the system will change its properties. For example, if user dislikes the combination of blue blouse with blue pants, the system will change the properties of the coordination strategy and not recommend this combination again.

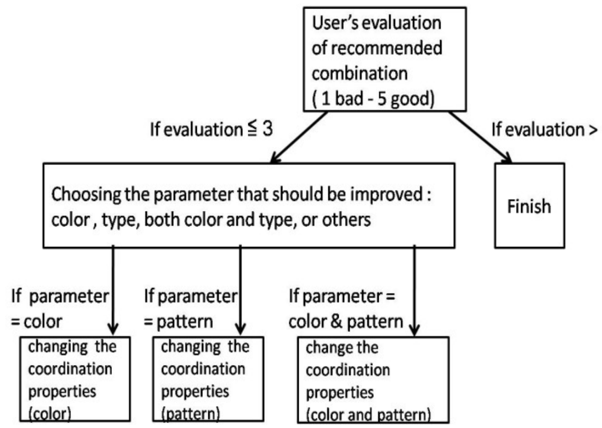

Figure 4.Flow chart of system learning

IV. Experimental Results

In order to evaluate the recommendations provided by this system, we performed two types of comparative experiment. The first experiment was an evaluation of the color recommendation, and the second was an evaluation of the recommendation as a whole.

A. Evaluation of the Color Recommendation

In the experiment, we evaluated the frequency of selection of 15 items in eight colors (three blue, six white, two brown, and one each in pink, green, gray, orange, and yellow). "Frequency of selection" is the rate of selection of a color, as expressed in Eq. (5).

$$\text{Frequency of selection} = \frac{\text{Number of times color appeared}}{\text{Number of articles of clothing in color}} \quad (5)$$

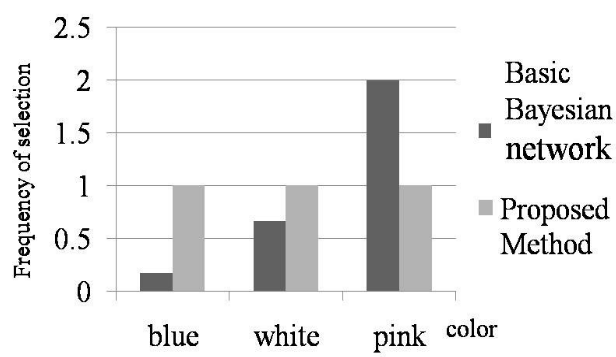

Figure5. Frequency of selection

The results for the frequency of selection of blue, white, and pink items can be seen in Figure 5. From them, we can conclude that the frequency of selection in the case of a simple system using a basic Bayesian network constructed only by the first step described in Section Ш A. is not balanced. For example, there are more clothing items available in white than in pink, but in the simple system, pink items are recommended more than white ones. Moreover, the simple system recommends fewer items than the proposed system. In the proposed network structure, color appeared depends on both clothing numbers and records could get better recommendation as shown in Table 3 which is the records of recommend colors and items identifier. Moreover, many more items could be recommended.

Table 3. Records of recommended colors and items id

Times	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Initial	BU (1)	BN (1)	GN (1)	GY (1)	PK (1)	OG (1)	YE (1)	WH (1)	BU (2)	BN (2)	GN (1)	GY (1)	PK (1)	OG (1)	YE (1)
Proposed method	WH (1)	WH (2)	BU (1)	WH (3)	BN (1)	WH (4)	BU (2)	GN (1)	WH (5)	GY (1)	WH (6)	BN (2)	PK (1)	OG (1)	YE (1)

(BU = Blue, BN = Brown, GN = Green, GY = Gray, PK = Pink, OG = Orange, YE = Yellow, WH = White)

B. Evaluation of Recommended Combinations

The system recommends combination to users on the basis of the following items from each person's wardrobe: 10-15 tops (including dresses) and 5-10 bottoms. In the experiment, the user could give an evaluation score to the recommended combination, excluding dresses, which did not combine with bottoms.

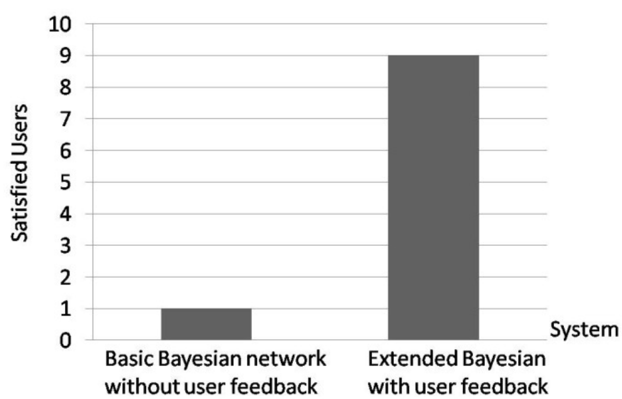

Figure 6. User evaluation of recommended outfits

Ten users experienced and evaluated two systems using the basic Bayesian network without user feedback system, and using the extended Bayesian network with user feedback. Each system suggests 14 recommendations to the user under the same conditions. Figure 6 illustrates the user evaluations of these system recommendations. The color combinations for tops and bottoms are recommended based on basic or common knowledge on color coordination by the system using the basic Bayesian network without user feedback. Most of the users did not expressed they liked the recommended color combination, such as red shirt and red skirt. The system without user feedback cannot avoid recommending such unsatisfied combinations without developers' efforts to modify the Bayesian network. The system with user feedback solves this problem by learning user's preference, and recommends personalized combination. The experimental results reveal that the system using the extended Bayesian network with user feedback can satisfy users much more than the system using the basic Bayesian network without user feedback.

V. CONCLUSIONS

This paper proposes a system that recommends clothing combinations to users from their wardrobe. The numbers of clothing items with different properties such as color will not be the same in a user wardrobe. The recommendation system is designed to recommends a clothing combination suitable to a specified situation and the user preference under the condition that every clothing item should be recommended with equal frequency. The system uses Bayesian networks and the feedback of recommendation output evaluation by the user. A special probability function for the Bayesian network is proposed to assure items recommended with equal frequency, and experimentally confirmed to well satisfy this condition in comparison with the simple Bayesian network neglecting the condition. The proposed system was experimentally used by users, where the users were satisfied much better than the system using the simple Bayesian network without the user feedback.

However, there are still many functions that can be improved upon in the proposed system. Our future plans include allowing the system to link to the Internet or refer to magazines to learn a user's preferences without direct user input; and providing more combinations, such as a hats, shoes, and accessories. Furthermore, other users' RFID tags could be read as another source of data for combination reference.

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