Current recommendation systems in healthcare are useful in providing recommendations on various care issues such as general health and remote monitoring. However, meeting the modern care needs of the elderly and people living with chronic diseases requires implementing designs that will allow corrective, preventive and predictive recommendations using modern technologies. This thesis presents designs that will enhance effectiveness of such systems and usefulness of their recommendations.
REAL-TIME RECOMMENDATION SYSTEMS IN HEALTHCARE
DESIGNING FOR AGED AND CHRONICALLY ILL PEOPLE
Adekunle Oluseyi Afolabi

REAL-TIME RECOMMENDATION SYSTEMS IN HEALTHCARE
DESIGNING FOR AGED AND CHRONICALLY ILL PEOPLE

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ABSTRACT

This study presents further ways recommendation systems can be used in healthcare. Traditional recommendation systems in healthcare have proved useful in providing recommendations on various care issues such as general health and lifestyle, quitting addictions, dietary advice among others. However, the primary focus of this study is getting the elderly and people living with chronic diseases to benefit better from recommendation systems because of the peculiarity of their conditions. The number of elderly and infirm people is expected to grow rapidly in developed countries in the years to come and most developing countries are likely to witness the same trend because of globalization. This will give rise to increasing costs of providing care for these valuable individuals in human and material terms. The possibility of reducing these costs while still providing effective care can be achieved by implementing a design that will allow corrective, preventive and predictive recommendations in a digitally structured home. By means of this, a minimum level of independence can be achieved by the elderly and ailing individuals while there will be a drastic reduction in the costs of care both in the short and long terms. In addition, there will be wise use of limited resources and improved care-giving. For people living with chronic diseases, the requirements gathered indicated the desirable need for a design that will allow a shared-environment for interactions and recommendations interchange. In view of this, a prototype mobile app called Recommendations Sharing Community for the Aged and Chronically Ill People (ReSCAP) was designed, developed, implemented and tested. In addition, as a result of lack of harmonized set of metrics and criteria for evaluation of recommendation systems in healthcare, this study sought to produce one. Therefore, sets of metrics and criteria have been produced, harmonized, and categorized. Two harmonization perspectives are presented while four categorization sets are developed. The categorization framework is flexible and easy to use. Hopefully this effort serves as a leap towards a universally acceptable sets of harmonized metrics and criteria for evaluation of recommendation systems.
Universal Decimal Classification: 004.89, 004.5, 004.382.73, 004.382.77


Library of Congress Subject Headings: Recommender systems (Information filtering); Mobile apps; Mobile computing; Application software; Intelligent agents (Computer software); Personal communication service systems; Self-help devices for older people; Assistive computer technology; Older people; Chronically ill; Medical care; Self-care, Health; Real-time data processing; Evaluation; Software measurement

Yleinen suomalainen ontologia: suosittelujärjestelmät; mobiilisovellukset; sovellusohjelmat; älykkäät agentit; älyteknikka; tietämysjärjestelmät; terveydenhoito; ikääntyneet; vanhukset; kroonikot; reaaliaikaisuus; arviointi
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Kuopio, 7th February 2019
Adekunle Oluseyi Afolabi
## LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>HCIS</td>
<td>Healthcare Information System</td>
</tr>
<tr>
<td>IoTs</td>
<td>Internet of Things</td>
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<tr>
<td>ReSCAP</td>
<td>Recommendations Sharing Community for Aged and Chronically Ill People</td>
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<tr>
<td>ReTReSCAP</td>
<td>Real-Time Recommendations Sharing Community for Aged and Chronically Ill People</td>
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<tr>
<td>RS</td>
<td>Recommendation System/Recommender System</td>
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<tr>
<td>HRS</td>
<td>Healthcare Recommendation System/Healthcare Recommender System</td>
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<tr>
<td>AI</td>
<td>Artificial Intelligence</td>
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<tr>
<td>TLC</td>
<td>Training Logic Concept</td>
</tr>
<tr>
<td>TGT-M</td>
<td>Trainee-Goal-Tutor and Means</td>
</tr>
<tr>
<td>EHR</td>
<td>Electronic Health Record</td>
</tr>
<tr>
<td>ICT</td>
<td>Information and Communication Technology</td>
</tr>
<tr>
<td>HRS</td>
<td>Health Recommendation System</td>
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LIST OF ORIGINAL PUBLICATIONS

This thesis is based on data presented in the following articles, referred to by the Roman Numerals I-V.


AUTHOR’S CONTRIBUTION

I) Author conducted the literature search and did the systematic review of the literature on recommender systems in Healthcare. The author also did the analysis, observed the gaps and proposed the solutions.

II) Expanding on the issues arising from the initial review of literature on recommender systems in healthcare, the author did the design of both the simplified and expanded architecture for integration of real-time recommendation system into home care system.

III) The author set up and implemented the process for identifying, harmonizing and categorizing metrics and criteria commonly used in the evaluation of recommendation systems in healthcare. Different views and categorization framework presented were done by the author.

IV) The author conducted the survey-style requirements gathering and analysis. The design of the entire architecture and the mobile app, Recommendations Sharing Community for the Aged and the Chronically Ill People (ReSCAP), were done by the author.

V) The idea on the use of evaluation criteria and metrics for strengthening the design of recommendation systems, in order to enhance their usefulness and acceptability, was conceived by the author. The procedure and the design for testing the viability of this idea were also done by the author.
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1 INTRODUCTION

In recent years, the world has experienced phenomenal growth in information available on the Internet with accompanied growth in the number of people searching for useful and helpful information. Producing high-quality recommendations and performing as many recommendations as possible per second for millions of users and items simultaneously are parts of intimidating challenges (Sarwar et al. 2001), for developers and users of recommendation systems in healthcare. Besides, the relevance of recommendations which often are user-defined is very important (Moreau et al. 2002) and can change when user’s interests, activities, and preferences change. Recommendation systems are nowadays more than just systems for matching and predicting user preferences. They are used for producing individualized recommendations as output or guide the users in a personalized and useful way towards meeting their aims (Burke 2002). This is especially true for those having health challenges and the elderly. Key attributes of a recommendation system therefore are individualization, interesting, and usefulness (Burke 2002, Olmo & Gaudioso 2008). That is the reason user-centered evaluation of recommendation systems has gained popularity, to determine to what extent a recommendation system is useful to the users (Pu et al. 2011, Knijnenburg et al. 2012). All these are seen from user’s perspective.

Traditional recommendation systems use the input data to predict potential preferences and interests of its users. Past evaluations of the user can be used as input data as well (Lu et al. 2012). A recommendation system collects information on the preferences of its users for a set of items using different sources of information for providing users with predictions and recommendations of items (Bobadilla et al. 2013). A recommendation system is as important in healthcare as it is in commerce and other sectors. It has brought about many changes and created new possibilities in healthcare domain. The typical implementation of a recommendation system known to many people is the search engine such as Google. The main characteristic of a recommendation system is that it can personalize interactions for each user. Personalization involves the design of a system that can infer the needs of each person and then satisfy those needs (Riecken 2000). In enhancing the usefulness of recommendation systems, they have been developed to meet the needs of users in different domains by using different methods and algorithms (Herlocker et al. 1999, Schafer et al. 2017). However, identifying the best possible algorithm for each domain or use case has been a challenge; since there is no general agreement among researchers neither on the required attributes nor on the metrics for these attributes (Herlocker et al. 2004). Addressing this challenge is one of the thrusts of this study.
Research questions answered in this study are
RQ1. What are the current and expected future trends in healthcare recommendation systems?
RQ2. How can healthcare recommendation systems meet the need of modern care giving?
RQ3. In what ways can the aged and the chronically ill benefit from the fusion of modern technologies and recommendation systems?
In this study, three important objectives are in the focus, namely
(1) Designing a system that will provide adequate care for the elderly while living in the comfort of their homes allowing corrective, preventive and predictive recommendations,
(2) Designing a platform where people living with chronic diseases can share recommendations and receive personalized attention, and
(3) Producing a set of metrics and criteria that can be used to determine usefulness of recommendation systems in healthcare.
With the expected growth in the number of old people in the coming decades and the attendant costs of providing health care along with required personnel (UNFPA 2018), the need for an alternative way of meeting the care needs of these people is urgent. Many researchers have pointed in the direction of home care driven by modern technologies (Taylor et al. 2008, Ten Haken et al. 2018, Tran et al. 2005, Andò et al. 2015). The implication is that most old people can live at home and still receive good care. In achieving this, most efforts have focused on medication reminders and use of sensors to monitor these people remotely. However, there is the need to go beyond these, come up with a design that will provide preventive, corrective, and predictive recommendations in real-time, and connect various stakeholders to enhance effective care giving. Although the design presented herein is heavily hardware-dependent and the initial costs of implementation may be high, the long-term benefits far outweigh the initial costs.
One good thing that a technological tool deployed in health domain can do is to meet the health needs of people for which it is designed. In doing so, the health needs of people living with chronic diseases were ascertained. The survey-style requirements gathering brought out the need for a community that will include patients with similar ailments along with their physicians and caregivers; up-to-date information about current treatment methods, drug discoveries, dietary advice, fitness and lifestyle, future expectations about the diseases are the essential features a system that will cater to their needs must have. These informed the designed implemented in a prototype mobile app called Recommendation Sharing Community for the Aged and Chronically Ill People (ReSCAP).
Based on the findings from this study that most recommendation systems in healthcare were not evaluated because there are no standard set of metrics and criteria to do so besides lack of harmonization in the metrics used for evaluation, the need to develop one became urgent. As a result, a set of metrics and criteria for
evaluation of recommendation systems in healthcare has been developed, harmonized, and categorized. Nine metrics and eleven criteria were harmonized. In harmonizing them, two logical perspectives namely Layman and Statistics were proposed, with none better than the other. The choice of which to use depends on individuals. However, for a better result, it is advisable that the two perspectives are considered. Besides, in categorizing metrics and criteria four priority sets have been proposed namely high priority, low priority, weak priority, and conditional high priority. The harmonized metrics and criteria can be used as a checklist during pre-requirements analysis and design. This has also been experimented in this study. The flexibility and ease of use is obvious in the categorization framework produced.

The rest of the thesis is organized as follows. Chapter two introduces the concept of healthcare information systems along with health data sharing and its effects in healthcare delivery. Chapter three discusses the relevance of recommendation systems in healthcare and the existing challenges. In chapter four, relevance of evaluation metrics and criteria in determining effectiveness of recommendation systems is discussed. Chapter five presents novel proposals and solutions. The conclusion and future work are presented in chapter six.


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