Modelling and Simulation in Engineering

Advanced Communication Models and Services for Smart World

Guest Editors: James J. Park, Ning Zhang, Neil Y. Yen, and Muhammad K. Khan

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Editorial Board

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Editorial

Advanced Communication Models and Services for Smart World

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Smart world (SW) represents a future communication environment featuring daily-life objects that continuously involve nonexpert users. The SW has rapidly emerged as an exciting new paradigm which integrates different active research areas such as Internet of Things (IoT), ubiquitous and pervasive computing, and peer-to-peer communications providing new exciting seamless services for the future IT environments. The systems for SW manage lots of sensors and mobile devices which continuously update information from the real-world objects, and most data are generated automatically through intelligent communication environments. This special issue aims to address advanced communication models and services for SW. It will solicit original research papers on topics including effective IoT, ubiquitous and pervasive computing, context-based services, machine-to-machine service model integration of legacy systems and services, security, business models, and novel applications of SW utilization.

During the working period, we received 20 submissions from at least 10 different countries where the corresponding authors were majorly counted by the deadline for manuscript submission. All these submissions were considered significant in the area of the promising services for the development of smart world, but, however, only two-fifth of them passed the first-round examination which is based on a strict and rigorous review policy. After a two-round review process, only 6 papers were accepted for being included in this issue. These accepted papers mainly look at our issue from the perspectives of smart business, intelligent web, e-commerce, semantic web, security and privacy, digital image processing, social network analysis, user behavior, mobile gateway, ubiquitous platform, mobile cloud, open API, human-computer interaction, emotion detection, wireless sensor network, network optimization, and power grid, which brought lively and focused discussions to the publics.

The paper titled "Getting Business Insights through Clustering Online Behaviors" explores the behaviors of online users. The major concern of this research is to identify clearly the frequent activities since the Internet has played a rather important role in present marketing environment especially to the companies. Authors utilized the revised K-means for the analysis of user behavior and attempt to obtain the clickstream data. Four major issues are investigated, which all point out the importance of the wide use of online media such as e-commerce marketing, social network, and online community.

The paper titled "An Intelligent Web Digital Image Metadata Service Platform for Social Curation Commerce Environment" introduces an intelligent web digital image information retrieval platform, which adopts XML technology for social caution commerce environment. To support object-based content retrieval on product catalog images containing multiple objects, we describe a multilevel metadata structures representing the local features, global features, and semantics of image data. To enable semantic-based and content-based retrieval on such image data, we design an XML-Schema for the proposed metadata. Authors also describe how to automatically transform the retrieval results into the forms suitable for the various user environments, such as web

browser or mobile device, using XSLT. The proposed scheme can be utilized to enable efficient e-catalog metadata sharing between systems, and it will contribute to improving the retrieval correctness and the user's satisfaction on semantic-based web digital image information retrieval.

The paper titled "Design of Mobile Gateway for Implementation of Smart Work System" considers a novel design of smart work environment. The smart work platform has been designed to meet the diverse needs from public users for efficient process of assigned tasks. For this reason, authors have developed a mobile gateway that is based on the communication server construction OPEN API development, management of mobile ID, protocol design, and design of SSL/TLS security tunnel. Also, authors developed a smart work platform that when you apply this, you are trying to provide information systems environment of mobile company.

The paper titled "Event-Related Potentials Related to Anxiety in Emotion-Attention Interaction" investigates ERP (event-related potential) characteristics using IAPS images, emotional faces, and emotional words as the emotional stimuli presented. The ultimate goal of this study is to detect the ERP components related to state and trait anxiety in an environment which requires target identification by inhibiting task-irrelevant emotional distractors, that is, interaction between emotion and attention. These neural characteristics can help us to understand the effects of anxiety on cognition processing and to determine therapy methods and therapy processes related to anxiety disorder.

The paper titled "Achieving Fair Spectrum Allocation and Reduced Spectrum Handoff in Wireless Sensor Networks: Modeling via Biobjective Optimization" considers the problem of centralized spectrum allocations in wireless sensor networks towards the three main expectations: (1) maximizing fairness, (2) reflecting the priority among sensor data, and (3) avoiding unnecessary spectrum handoff. This problem is studied through a multiobjective mixed integer nonconvex nonlinear programming that is definitely difficult to solve at least globally without any aid of conversion or approximation. To tackle this intractability, authors first convexify the original problem using arithmetic-geometric mean approximation and logarithmic change of the decision variables and then deploy weighted Chebyshev norm-based scalarization method in order to collapse the multiobjective problem into a single objective one. Finally, authors apply simple rounding method in order to obtain approximate integer solutions. The results obtained from the numerical experiments show that, by adjusting the weight on each objective function, the proposed algorithm allocates spectrum bands fairly with well observing each sensor's priority and reduced spectrum handoffs.

The paper titled "Computer Aided Modeling and Analysis of Five-Phase PMBLDC Motor Drive for Low Power High Torque Application" discusses the scenario to achieve high torque at low power with high efficiency. A new five-phase permanent magnet brushless dc (PMBLDC) motor design was analyzed and optimized. A similar three-phase motor having the same D/L ratio (inner diameter (D) and length of the stator (L)) is compared for maximum torque and torque ripple of the designed five-phase PMBLDC motor. Maxwell software was used to build finite element simulation model of the motor. The internal complicated magnetic field distribution and dynamic performance simulation were obtained in different positions. No load and load characteristics of the five-phase PMBLDC motor were simulated, and the power consumption of materials was computed. The conformity of the final simulation results indicates that this method can be used to provide a theoretical basis for further optimal design of this new type of motor with its drive, so as to improve the starting torque and reduce torque ripple of the motor.

The scenario of smart world and its related systems, applications, and services has drawn attentions to the publics and indeed caused great changes to our daily lives. With the success in the organization of this special issue, it becomes possible for researchers (and interesting readers as well) who have been engaged in this or related areas to receive state-of-the-art information, gain experiences, and further bring about the benefits in this promising area of study. We, the guest editors, also envision the advanced stimulation of development of innovative services and solutions in this area can be achieved in the coming future.

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Review Article

Getting Business Insights through Clustering Online Behaviors

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This study aimed to explore the online users' behaviors. Since the Internet was introduced to the market, the various and frequent online activities have increased, and it becomes more important for the businesses to understand the online users. Therefore this study analyzed the online users' behaviors and segmented the users by using K-means clustering method using actual clickstream data. There were four different research questions and, thus, four different sets of segmentations. It was found that many people find much of entertaining from online using SNS, games, and so on. In addition, some people only have access to a few specific websites. Some use the online service regularly every day while others use it in a very irregular pattern. People were divided into two groups, weekday group and weekend group. People are likely to be using the Internet either on weekdays or at weekend. Teenagers and people in their 50s are more likely to use it during weekend. In addition, teenagers also show different time zone (e.g., overnight) to use the Internet from other age groups. These results can shed light on understanding what consumers do online and what they are interested in currently and on decision making in marketing strategy.

1. Introduction and Research Questions

As the Internet technology has been advanced, the usages of Internet service have been rapidly increasing. People in the USA have used the online service longer ever since the Internet introduced. It increased from 11.9 hours to 12.9 hours per month. In addition, people use online service in many different areas such as download, games, and shopping [1–3]. As the use of the Internet increases, the users have become more active online. Therefore, it has become important for the businesses to understand the online users.

There have been many studies done on online behavior. Most of the studies on the Internet and the users have tried to understand who they are and what they are doing online [4–6]. These studies conducted segmentation and grouped the online users by such variables as age, gender, and lifestyle [7–9]. The studies have used mostly survey data, which indicates what online users perceived they did online.

This study, however, used actual clickstream data, which can give us the clear ideas about what they have done instead of what they perceived they have done. With the clickstream data, proper variables were identified. Using the K-means clustering method, this study attempts to find different groups of online users so that customized services and value can be provided to the users based on their patterns and preferences of websites and their functions.

We attempted to answer the following research questions.

(Q1) What do the online users use the Internet for?

(Q2) What are the characteristics of online behaviors?

(Q3) When do the online users use mostly the Internet during the week and weekend?

(Q4) When during a day do the online users usually use the Internet?

2. Experiment and Results

2.1. Data Description. The data analyzed was from 5,000 online users, and about 150 millions of transactions from July 2012 to June 2013 were used. The transactions include user id, time and date, accessed URL, and dwell time.

2.2. Analysis Method. Clustering is one of the data mining methods that divide multivariate data into several different groups by its similarities of characteristics. Clustering is widely used to understand the characteristics of consumers and markets in the business domain, and algorithms used are K-means clustering, Kohonen Network, TwoStep Clustering, and so on. As other studies [5, 6, 10], this study also used the K-means clustering method with IBM SPSS modeler 15.0 to segment the markets. The K-means clustering method is relatively easy to analyze and effective to use different forms of data while it is difficult to decide the appropriate number of clusters. In order to choose the optimal numbers of clusters, we used Silhouette measure which is the average, over all records $(B-A)/\max(A, B)$, where A is the record's distance to its cluster center and B is the record's distance to the nearest cluster center that it does not belong to.

According to the four research questions above, four different sets of segmentations were found. They are (1) topic segmentation, (2) behavior characteristics segmentation, (3) weekday segmentation, and (4) time segmentation.

2.3. Results. (Q1) What do the online users use the Internet for? Topic segmentation.

To answer the first question, data was clustered by the topics of websites that users visited. Table 1 shows the result of topic segmentation, which found five different segments.

The largest group is Cluster-4, "information consuming and entertainment group," which includes 38.7% of sample, 1,933 persons. They are mostly the main users of the Internet, who use search, community, SNS, entertainment, game, other services, and business and economics related websites.

Cluster-1 is "portal service group." They mostly use the portal services in the Internet, which account for 19.3% of total sample. "Finance and public service group" is Cluster-2. They use mostly finance information and public services, and this group is the smallest with 3.8% of total sample (191 persons). Cluster-3 is "email and news group" with 18.6% of total sample, and they are users of email, news, and Internet and computer related websites. Cluster-5 is "shopping group," of which people use the Internet mostly for shopping and they account for 19.7% of total sample. Therefore, around 20% of online users enjoy mostly online shopping, not other Internet services.

(Q2) What are the characteristics of online behaviors? Behavior characteristics segmentation.

Second set of segmentation is about the behavioral patterns of online users. The variables for this clustering are COV, COVERAGE, D_COV, SCH_KEYWORDS, and VDAYS. The explanation of each variable is provided in Table 2. With those variables, four segments were found as shown in Table 3.

The largest group in Table 3 is Cluster-4, "various daily access group." It includes 46.8% of total sample. In this group, variation in daily Internet usage is big. That is, the online users are not using the Internet consistently during a year. For some days, people use it a lot, while in some other days they do not use it much. Since it is the largest group, mostly women and men belong to this "various daily access group" (46% of men and 48% of women).

People in Cluster-1 are in "everyday access group," the second largest group (around 20% of total sample). They access the Internet everyday consistently often, but not many different websites.

People in Cluster-2 are in "a few important websites access group," the third largest group with 17.5% of total sample. They use only small number of websites and they tend to visit those websites in a desultory fashion. They only use the Internet for a few topics.

The last group of people in Cluster-3 is in "many different websites access group." They are likely to search many different keywords, and thus they are most likely to visit many different categories of websites. It is the smallest group with 15.8% of total sample.

For "various daily access group" and "many different websites access group," higher percentage of women are included than percentage of men. On the other hand, "a few important websites access group" and "everyday access group" have higher percentage of men than percentage of women.

With all ages, higher percentages of people are included in "various daily access group." In particular, for teenagers, 68.9% of them are in this group, while for other ages mostly 44~54% of them are in the group. For people aged 10s and 20s, "many different websites access group" is the second largest group with 11.5% of people aged 10s and 23.3% of people aged 20s. However, for people aged 30~50s, the second largest group is "everyday access group" and then "a few important websites access group."

(Q3) When do the online users mostly use the Internet during the week and weekend? Weekday segmentation.

To answer the question, the Internet usage in each day during week is calculated. As shown in Table 4, two groups were found. Cluster-1 is "weekdays group" and Cluster-2 is "weekend group." As expected from the title of group, "weekdays group" uses the Internet usually during weekdays from Monday to Friday, while "weekend group" uses the Internet during weekend from Saturday to Sunday more often.

People in their 10s and 50s are using the Internet during weekend slightly more than weekdays.

In "weekdays group" around 60% of people aged 20s are included. For people aged 20s, 30s, and 40s, more users are using the Internet during weekdays (more than 50%). However, as age increases, percentages in "weekdays group" are decreasing while more people use the Internet at weekend. And finally for people in their 50s, "weekend group" (51.3%) is slightly higher than "weekdays group" (48.7%).

(Q4) When during a day do the online users usually use the Internet? Time segmentation.

Three groups were found as shown in Table 5. A group of people who are in Cluster-1 are using the Internet usually afternoon time, from noon to 11 pm which is called "afternoon group." However they are usually not using the Internet much. Cluster-2 is "overnight group" which is using the Internet from 6 pm to 5 am. Cluster-3 is "working hour group" who uses the Internet from 6 am to 5 pm.

"Afternoon group" have shown that they are not the heavy users, which account for 31%. Almost half of people (45%) use the Internet during working hours, from 6 am to 5 pm. The smallest group of people is "overnight group." They stay up all night using Internet.

Table 1: Topic segmentation.

	Clusters				
	Input (predictor) importance: 1.0, 0.8, 0.6, 0.4, 0.2, 0.0				
Cluster	1	2	3	4	5
Label	Cluster-1	Cluster-2	Cluster-3	Cluster-4	Cluster-5
Description	Portal service group	Finance and public service group	Email and news group	Information consuming and entertainment group	Shopping group
Size	19.3% (964)	3.8% (191)	18.6% (929)	38.7% (1933)	19.7% (983)
Inputs	CT_Finance	CT_Finance	CT_Finance	CT_Finance	CT_Finance
	CT_Mail	CT_Mail	CT_Mail	CT_Mail	CT_Mail
	CT_Portal	CT_Portal	CT_Portal	CT_Portal	CT_Portal
	CT_Shopping	CT_Shopping	CT_Shopping	CT_Shopping	CT_Shopping
	CT_Search	CT_Search	CT_Search	CT_Search	CT_Search
	CT_Shopping support	CT_Shopping support	CT_Shopping support	CT_Shopping support	CT_Shopping support
	CT_Public services	CT_Public services	CT_Public services	CT_Public services	CT_Public services

Table 1: Continued.

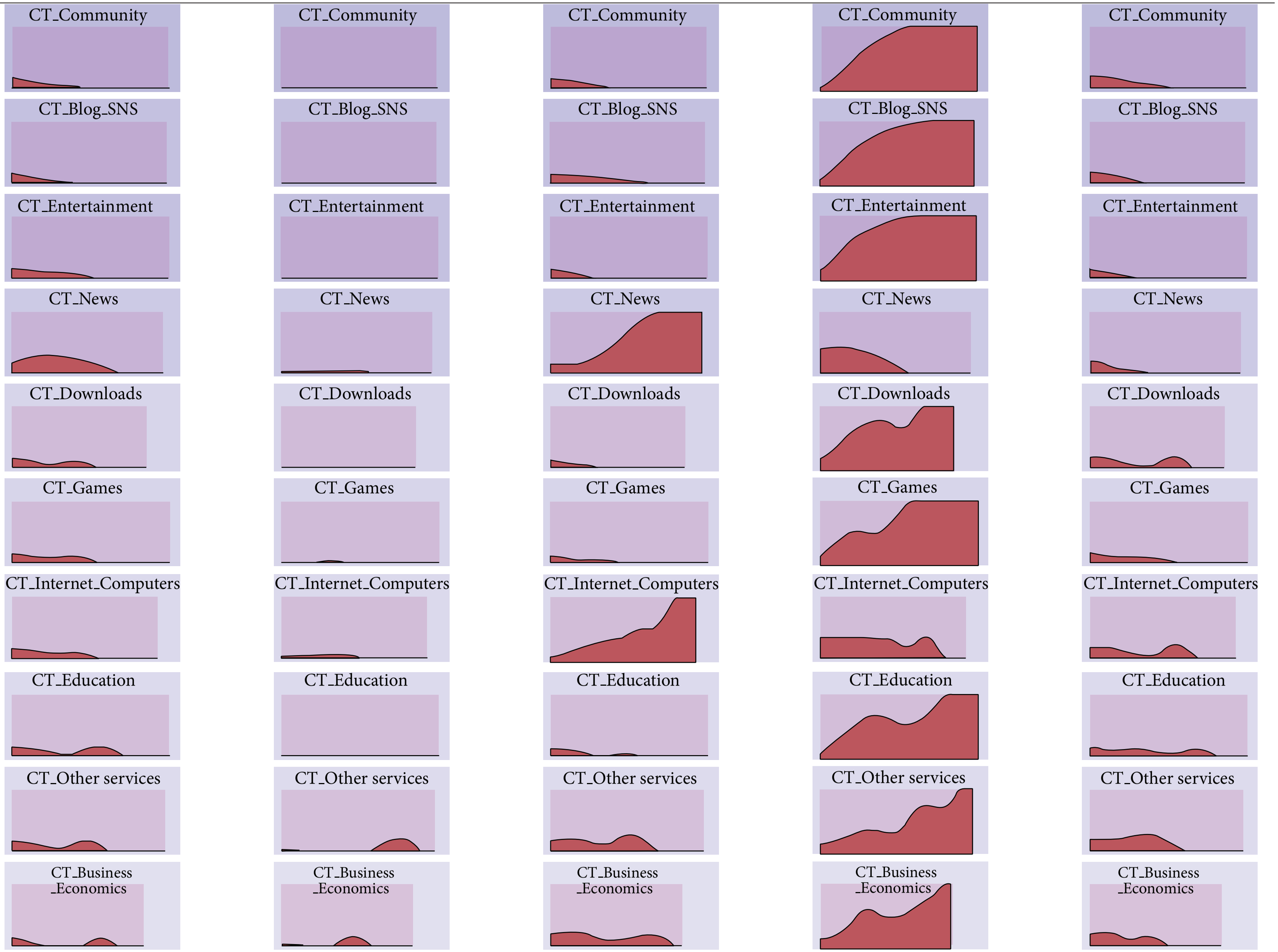
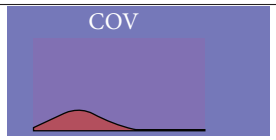
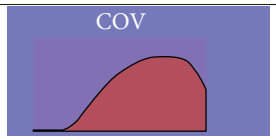
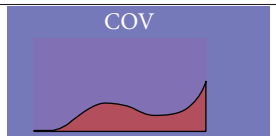
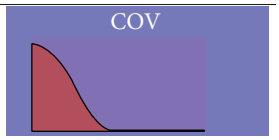
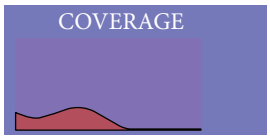
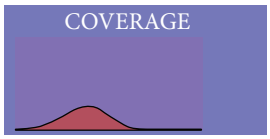
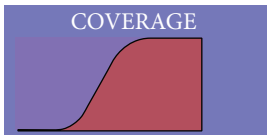
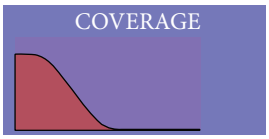
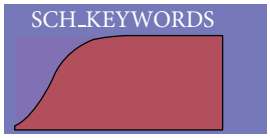
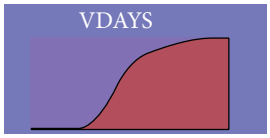
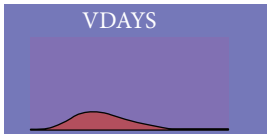
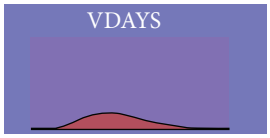
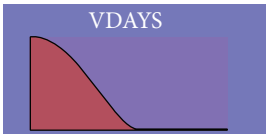
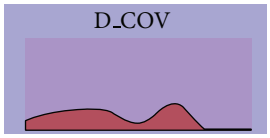
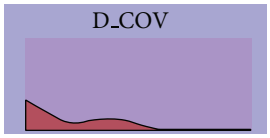
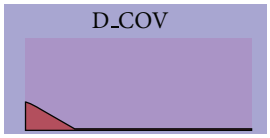
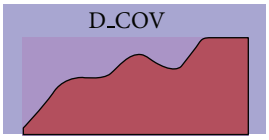


Table 2: Segmentation variables for behavior characteristics.

Variable	Explanation
COV	The coefficient of variation of dwell time per site ("standard deviation/average" of dwell time per site)
COVERAGE	The degree to which each individual visits diverse category websites among the 1231 website categories
D_COV	The coefficient of variation of dwell time per day ("standard deviation/average" of dwell time per day)
SCH_KEYWORDS	The number of different keywords that each individual searches in a year
VDAYS	Total number of days to access the Internet in a year

Table 3: Behavior characteristics segmentation.

	Clusters			
			Input (predictor) importance: 1.0, 0.8, 0.6, 0.4, 0.2, 0.0	
Cluster	1	2	3	4
Label	Cluster-1	Cluster-2	Cluster-3	Cluster-4
Description	Everyday access group	A few important websites access group	Many different websites access group	Various daily access group
Size	19.9% (997)	17.5% (873)	15.8% (791)	46.8% (2339)
Inputs				
				
				
				
				

As expected, 62% of teenagers are in "overnight group," while all other ages (20s~50s) are mostly (around 50%) in "working hours group." 32% of men are in group 1 and 25.2% of men are in group 2, while 29.9% of women are in group 1 and 22.2% of women are in group 2.

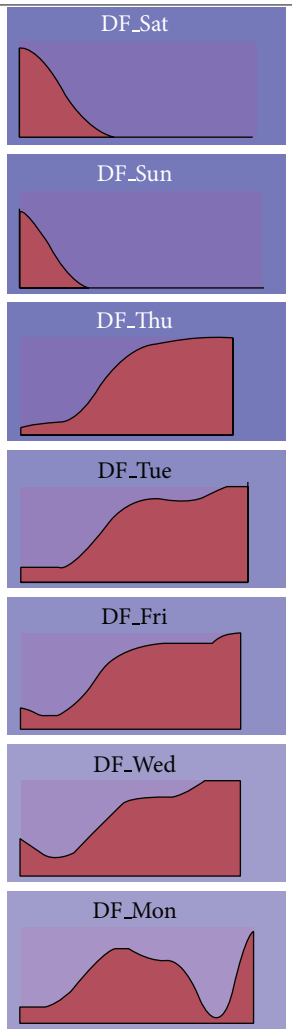
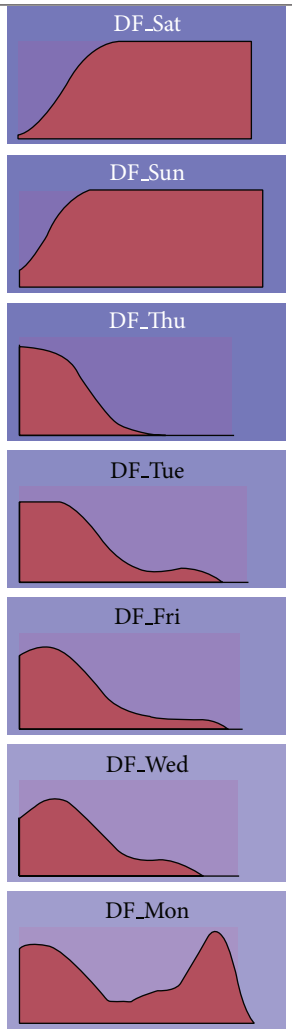
For "working hours group," 47.9% among women are included, which is higher percentage than men (42.7% among men are included in "working hours group"). However "overnight group" and "afternoon group" show higher percentages among men than the percentage among women.

3. Implication and Concluding Remarks

This research aims to identify better segmentation of online users based on their behaviors using actual clickstream data. In order to understand the online users' behaviors better, four different research questions were asked.

First, what do the online users use the Internet for? The results indicate that around 40% of people are enjoying entertaining, having relationships with people through online, information search, and business related websites.

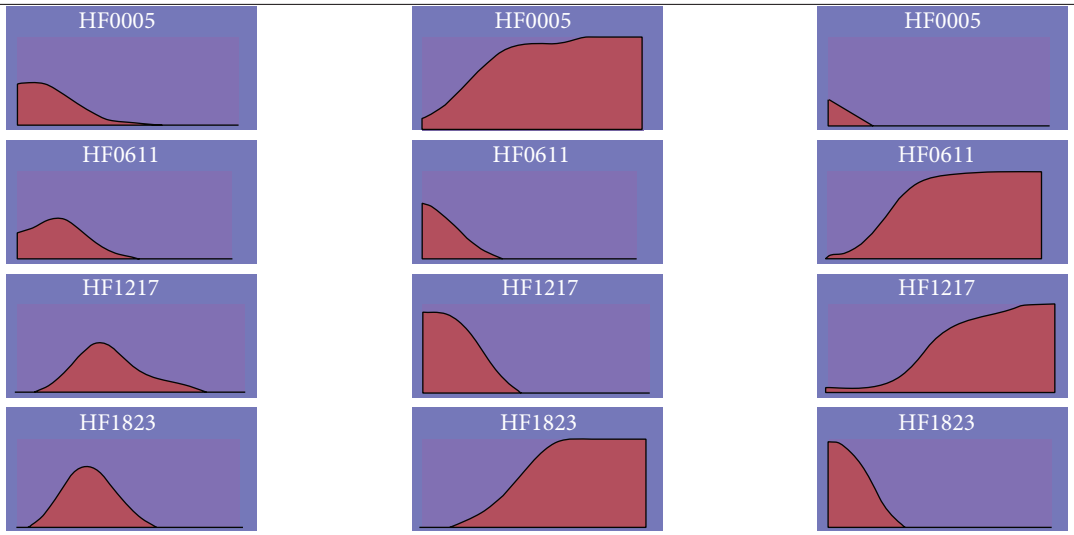
Table 4: Weekday segmentation.

	Clusters	
	Input (predictor) importance 1.0 0.8 0.6 0.4 0.2 0.0	
Cluster	1	2
Label	Cluster-1	Cluster-2
Description	Weekdays group	Weekend group
Size	54.3% (2717)	45.7% (2283)
Inputs		

That is, 40% of people use the Internet for various general uses. On the other hand, three other groups were found who are narrowly focused on certain use of the Internet such as a shopping focused group, a portal focused group, and a computer, email, and news focused group. In addition small portion of people (3.8%) were found to use the Internet for finance related and public services. In sum, many people who use the Internet enjoy the various entertainment elements while some are focused on specific things. Therefore, it is considerable to develop new contents for people with different interests based on what they are interested in while being online and what they usually do online.

Second, what are the characteristics of online behaviors? People were divided into two groups in big category, which are a group with various usages and the other group with a few topics focused. Most of the people, around 80%, are found to be a few topics focused. They are further divided into three groups; "various daily access group," "everyday access group," and "a few important websites access group". On the other hand, a group with various usages is called

Table 5: Time segmentation.

Clusters			
	Input (predictor) importance: 1.0, 0.8, 0.6, 0.4, 0.2, 0.0		
Cluster	1	2	3
Label	Cluster-1	Cluster-2	Cluster-3
Description	Afternoon group	Overnight group	Working hour group
Size	31.3% (1565)	24.0% (1201)	44.7% (2234)
Inputs			

"many different websites access group" and they are likely to search many different keywords, and thus they are most likely to visit many different categories of websites. Based on this different patterns of behaviors, the decisions about how to communicate with consumers via online can be made.

Third, when do the online users mostly use the Internet during the week and weekend? There were two groups found, which are "weekdays group" and "weekend group." Teenagers and people in their 50s are included in "weekend group" slightly more than in "weekdays group" while people in their 20s~40s are more in "weekdays group" than in "weekend group." Among the people in their 20s~40s, people aged in 20s are likely to be in "weekdays group" more than people aged in 40s. It indicates that as people become older, they do not have enough time for the Internet during weekdays. It implicates that for teenagers it is good to have promotion during weekend. During weekdays office workers can be a target for communication or promotions.

Fourth, when during a day do the online users usually use the Internet? Almost half of people (45%) use the Internet during working hours, from 6 am to 5 pm. 62% of teenagers use the Internet overnight. It implicates that, for different age groups, the different time zones for on-time communication would be worth considering.

In sum, the study attempted to explore the online users' behaviors now that it has been more than 20 years since the Internet was introduced to the market using the clickstream data which is not the perceptions of users. It may shed light on understanding online behaviors of people and help the businesses make better strategy to communicate with their customers using the online devices.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Design of Mobile Gateway for Implementation of Smart Work System

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In the development of new technologies based on mobile system, there is a growing interest as a fundamental technology. In particular, in order to realize a mobile office and mobile phones, conferencing remote document is a technique that can realize smart network services solutions with enhanced real-time communication, real-time information sharing, and collaboration. Therefore, in this paper, the design meets the diverse needs of customers and the smart work platform mobile-based fast and conveniently it is trying to develop. For this reason, I have developed a mobile gateway that is based on the communication server construction OPEN API development, management of mobile ID, protocol design, and design of SSL/TLS security tunnel. Also, we developed a smart work platform that you apply this, you are trying to provide information systems environment of mobile company.

1. Introduction

In the sense of recent office moves, mobile office is increasingly popular. In other words, the smart phone is opening the era of the popularization of the mobile Internet, starting your day with a smartphone, finishing with a smart phone; the influence of mobile generation is increasing [1]. However, there is a drawback operating system for mobile devices and the kind of smartphone that limited Korea. In addition, the intended uses are also limited to personal use; the introduction of business-based solution that can be utilized in educational institutions and companies has been accelerated. Smartphone is more likely to be used as a personal office equipment as well as necessary office equipment and supplies used by personal PC, a notebook in business there is a need for this type of software development work. Reflecting this, the office is used to mean a place where smart phones. In other words, the introduction of mobile office companies to increase steeply advantages of immediate, short time, productivity, efficiency, increase usability, competitive [2, 3].

Therefore, in this paper, I try to develop a smart work platform of mobile gateway-based rapid and inexpensively to meet the diverse needs of our customers (Figure 4). For this reason, the development of mobile gateway can be used as a first stage, to be shared by various applications and Web services identity information of the user. In two stages, the gateway between the mobile terminal and the SSL/TLS End-to-End strengthen the security services provided through a security tunnel. In order to provide office services from the terminal finally subject was studied by developing smart work platform.

2. Current Situation of Technique

2.1. Domestic Technology Trend. Domestic mobile office market was a time when the extent of setting up a wireless network in your company has been to represent mobile office 10 years ago. The main terminal of the first generation of mobile office environment had a wireless network device is utilized notebook PC. It came into the second generation that the

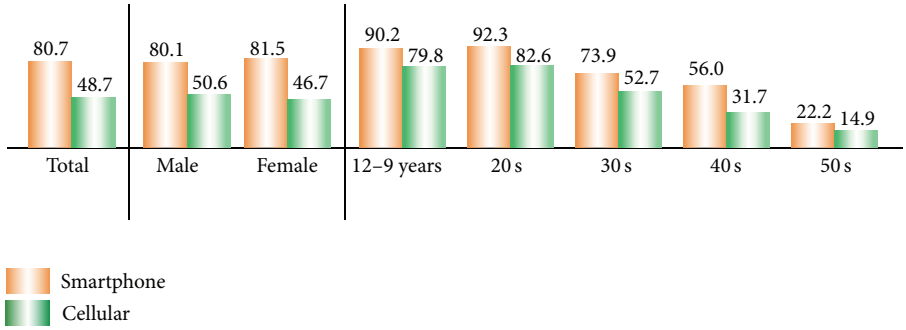

Figure 1: Wireless Internet usage.

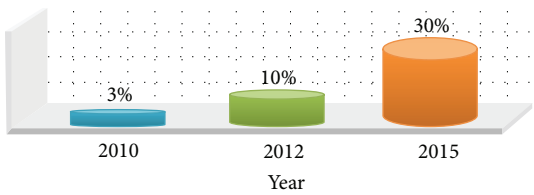

Figure 2: Smart work creates an environment of workers of 30% in 2015.

mobile device is more diverse, will be started to utilize a variety of mobile devices including PDA, smart phone, tablet PC (Figure 3). Currently, many companies are utilizing the mobile office on the level of the second generation. Service can include intranets within the corporate from the mobile device and is used in conjunction with customer relationship management (CRM), enterprise resource planning (ERP), Supply Chain Management (SCM), and so forth, Step 3 mobile office. It is possible to retrieve service related information, such as when this step is that the user has a smart phone or a PDA, a tablet PC. Another object of the present invention is a mobile office environment which can be processed in real time to conduct a wide range of activities such as a remote document approval that is mounted. Currently, technology solutions in domestic is a state that depends on overseas market solutions in the entry time. Domestic is the rudimentary stage which entered the market formed, but mobile office market is expected to grow to 5.9 trillion yen in 2014 from 2.9 trillion won in 2009 [4, 5].

2.2. Overseas Technology Trends. If going overseas is a step of fixing the service to starting with the IBM a mobile office service performed by a program called Smart (SMART, Space Management And Required Technology). It looks like it will continue to grow to $90 billion in 2015 from $61 billion in 2009 (Figure 2).

British Telecom (BT) was the first that started in Europe FMC service, but due to technical limitations, targeted at individual customers "BT Convergence" service to give up, to concentrate on the B2B market that they now have. On the other hand, they issued a "Wi-Fi Calling for Business" based on the UMA in conjunction with Blackberry; T-mobile is a solution that extends the mobile communication PBX such as Avaya and Cisco in (Private Branch eXchange) systems provide to AT&T. British Telecom (BT) may be able to connect the Internet, mobile phone, and wireless Internet access via a (MobileXpress SW) Mobile Express software, to perform a business process by connecting to the application or the company intranet from anywhere in the world possible (Figure 1) [6, 7].

Now, I support up to 650 pounds cost of Internet connection, such as the purchase of e-mail forwarding service (P.O. Box) and of office furniture in the telecommuter. As a result, productivity is increased to 20–60% from the residence office staff, sick leave absence rate of employees was reduced 63% [8].

3. Implementation of Smart Work System

In this paper, we conducted a study to develop a smart work platform of mobile gateway-based convenient and quick to fit different requirements of our customers (Figure 5). For this reason, depending on the smart work platform is in conjunction with the company's existing information systems and we have developed a smart work platform of mobile gateway base for small- and medium-sized enterprises, which can significantly reduce building operating costs. Finally, we conducted a survey by classifying the development of smart work platform to which the development of the mobile gateway is applied [9, 10].

The mobile gateway was developed by classifying into three stages. In one step, we have developed an API in conjunction with the integrated management of mobile ID. Therefore, it is managing the identities to be used and offline services have been developed in the form of the Open API. We also develop a management protocol issue of mobile ID, update, disposal, user-friendly and establish trust early we have developed a key technology exchange and efficient

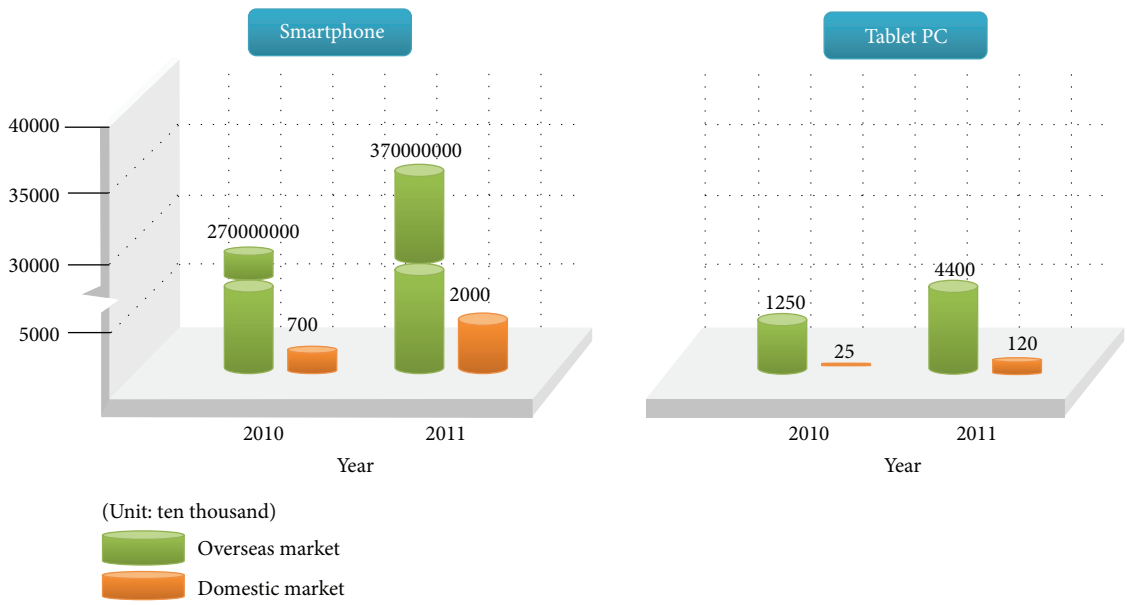

Figure 3: Smart device usage.

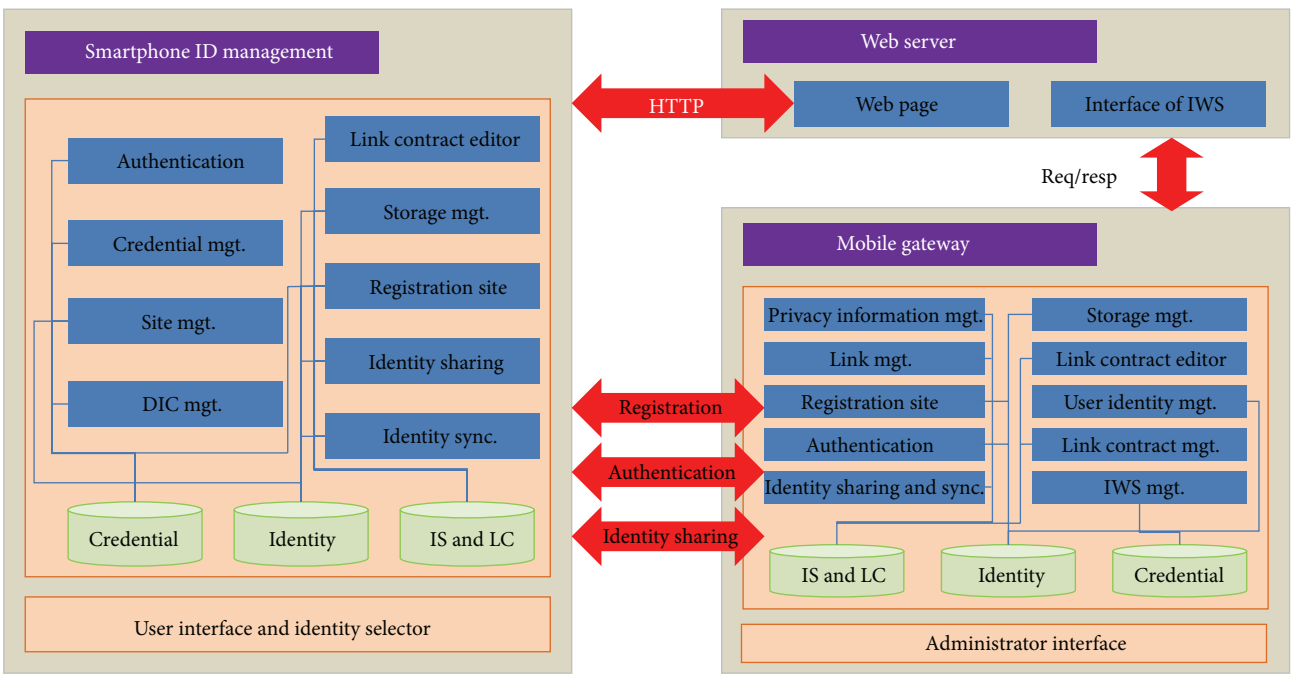

Figure 4: Design of mobile gateway.

authentication. In Step 2, we have developed the security features of End-to-End and terminals. Therefore, we have developed a SSL/TLS tunneling security to provide security features of End-to-End and terminals. In step 3, was developed for embedded mobile gateway. Therefore, we developed a mobile gateway box using embedded OS, which was communicating with the mobile office server for PC. Also, I have to prepare a gateway that takes into account the performance and scalability [11].

In the smart work platform, based on the mobile gateway, we have developed a server/client form. Smart work platform of mobile gateway-based has developed a remote management capabilities authentication, LBS/GIS, of the terminal. In other words, I have developed a smart work platform that provides services such as version control of remote administration of client terminal, authentication, LBS/GIS, and the mobile office. In addition, we have developed a data conversion function of the cellular phone. As a result, it

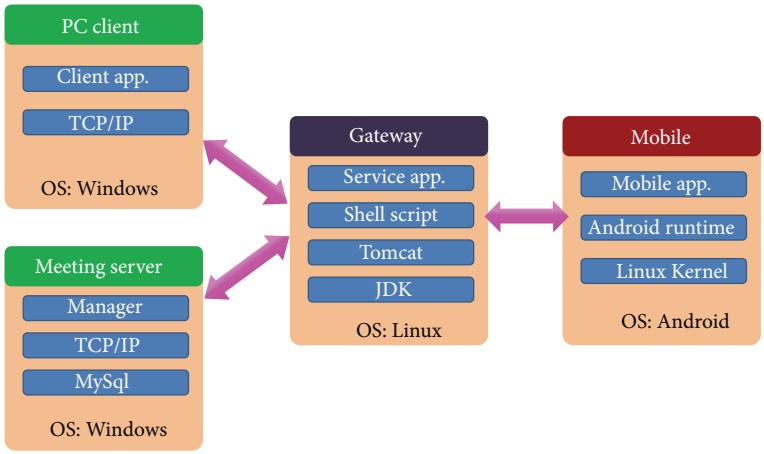

Figure 5: Smart work system construction plan.

provides a mobile data conversion function that specializes in business process MS Office document, HWP, such as PDF. Finally, I have developed a smart work platform based on server/client architecture [12].

Smart work platform server is provided to register and manage the terminal, conference registration and management of data, the mobile client deployment, and update capabilities. Then, in the client platform of smart work, I provide smartphone, mobile services and agent platform, and a mobile services platform electronic program.

In the field of mobile gateway-based server platform technology, smart work platform of mobile gateway-based, which was developed in this paper, it is possible to expand the mobile Web server application art. Further, it is possible by technical developments for executing Web server from the mobile terminal, to develop SW which operatively interconnects the PC environment with the mobile module. As a result, it is possible to develop the new technology of the next generation, such as remote monitoring collaboration support system and real-time decision making of mobile phone-based, real time.

4. Conclusions

In this paper, we studied a technique capable of releasing a convenient smart work business mobile market is steadily increasing current is applied. Therefore, we have developed a smart work platform mobile gateway base capable of increasing the efficiency of a company's information system. Smart work platform was developed integrated management of mobile ID in the form of Open API, identity management, protocol management and developed a mobile gateway to the application of the security technology of End-to-End.

In addition, the smart work platform, authentication, remote management of the terminal, data conversion, and developed server/client technology were applied.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

An Intelligent Web Digital Image Metadata Service Platform for Social Curation Commerce Environment

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Information management includes multimedia data management, knowledge management, collaboration, and agents, all of which are supporting technologies for XML. XML technologies have an impact on multimedia databases as well as collaborative technologies and knowledge management. That is, e-commerce documents are encoded in XML and are gaining much popularity for business-to-business or business-to-consumer transactions. Recently, the internet sites, such as e-commerce sites and shopping mall sites, deal with a lot of image and multimedia information. This paper proposes an intelligent web digital image information retrieval platform, which adopts XML technology for social curation commerce environment. To support object-based content retrieval on product catalog images containing multiple objects, we describe multilevel metadata structures representing the local features, global features, and semantics of image data. To enable semantic-based and content-based retrieval on such image data, we design an XML-Schema for the proposed metadata. We also describe how to automatically transform the retrieval results into the forms suitable for the various user environments, such as web browser or mobile device, using XSLT. The proposed scheme can be utilized to enable efficient e-catalog metadata sharing between systems, and it will contribute to the improvement of the retrieval correctness and the user's satisfaction on semantic-based web digital image information retrieval.

1. Introduction

The information services platform manages large-scale information assets compiled from heterogeneous data resources. With the information services platform, users can search for appropriate information services and effectively compose new services to satisfy their requirements and increase the value and utilization of information assets. Furthermore, the platform enhances the development of information analysis services by helping users discover correlations among large-scale and diverse data such as science data on the global environment. We harvest and analyze data provided by various research organizations, newspaper articles, and web contents describing society, and we cross-search and integrate data related to various events and phenomena. Moreover, composition of these services enables users to develop applications adaptive to changing environments, such as events and shopping in the real world [1].

Recently, the usage of web digital image information is ever increasing with the rapid development of multimedia technology. Multimedia data is commonly used on wired and wireless internet in various industrial areas including information technology area. A number of research groups are exploring different approaches to provide and transform multimedia information on various client devices, such as web browsers, iPad, and smart phones [2]. There are also various types of multimedia data in various industrial areas and they become quite essential to provide standard formats of multimedia information to allow data exchange and sharing through the Internet. One of the well-known standards for the description of multimedia information is MPEG-7. A lot of efforts have been made to represent MPEG-7 based

multimedia information in XML format [3], but they are still in an early stage.

Among multimedia data, images are widely used in various applications. Retrieving images attract high and increasing interest from the wide range of applications, such as medical information systems, biological information systems, electronic museums, and e-commerce electronic catalogs. There have been a lot of research works to support content-based retrieval on images. But, we found that most of the previous research was focusing on content-based retrieval of images based on image features in global level [4].

We envision the future web as pages containing both text and semantic markup. Current web digital image information retrieval techniques are unable to exploit semantic knowledge within documents and hence cannot give precise answers to precise questions [5].

This paper is an effort to make web digital image information better utilized by adopting XML technology. To support object-based content retrieval on product catalog images containing multiple objects, we describe multilevel metadata structures representing the local features, global features, and semantics of e-catalog data. To enable semantic-based and content-based retrieval on such image data, we design an XML-Schema for the proposed metadata and show how to represent such metadata using XML documents. We also describe how to automatically transform the retrieval results into the forms suitable for the various user environments, such as web browser or mobile browser, using XSLT. The proposed scheme can be easily implemented on any commercial platforms supporting XML technology. We strongly believe that the proposed schemes can be utilized to enable efficient image metadata sharing between systems. Also, it will contribute to the improvement of the retrieval correctness and user's satisfaction on semantic-based web digital image retrieval.

The remainder of this paper is organized as follows. Section 2 describes overview on previous image retrieval systems and XML related technologies. Section 3 explains the proposed platform architecture. In Section 4, we show a multilevel web digital image metadata modeling and represent our modeling results using XML-Schema. In Section 5, we explain the prototype implementation of intelligent web digital image metadata service platform by using a dynamic XML document search technique. Finally, Section 6 concludes and summarizes the paper.

2. Related Work

The previous image searching techniques can be classified into three branches. First approaches are simple search techniques based on keywords, which describe subjects or titles [6]. Formatted data on images and image file names are stored in databases, while images are stored in external files. Searching operations are usually performed by using descriptive keywords. Automatic extraction of image related keywords from HTML web pages is possible, but unrelated or unimportant words can be selected deteriorating retrieval performance.

Second approaches are content-based image retrieval techniques using feature vectors. Multidimensional vectors representing color, texture, and shape features of images are commonly used [7]. Image metadata are added within databases or file systems to support similarity-based searching on image data [8, 9].

Third approaches are hybrid style of above approaches. Feature vectors are extracted by image preprocessing and metadata information, such as keywords, semantic information, and visual information, which are manually or automatically added [10, 11].

2.1. Image Searching Techniques. Image metadata are added within databases or file systems to support similarity-based searching on image data [12–15]. Some systems support keyword only retrievals and others support content-based image retrievals [16, 17]. In the latter approach, image retrievals based on feature information, such as average colors, color histograms, texture patterns, and shape objects, are supported. Most of them are developed for image database applications [18, 19]. Representative examples are QBIC [20], Safe, VisualSEEK [21], Photobook [22], WBIIS, Chabot [23], and Blobworld [24]. One of the most recent research works has been done by the SIMPLIcity system which supports content-based image retrieval based on the color, texture, and shape features, while it is increasing matching correctness by utilizing local features on regions [25–27]. In the medical domain, the KMeD (Knowledge-Based Medical Database) system utilizes semantic modeling focusing on object shapes and spatial relationships between them [28, 29].

2.2. XML Techniques. XML is a standard markup language proposed for data exchanges on the web [30]. XML is proposed by W3C to describe next generation web pages [31, 32]. In database field, there have been a lot of research efforts to store, index, and retrieve XML documents in database systems [33, 34]. Some systems are stand-alone, while others are built on top of relational databases or object-relational databases [35, 36]. Another related research trend is to transform normal data stored in databases into XML documents for efficient integration of heterogeneous information resources [37]. New query languages, such as Xpath, XML-QL, XQL, Quilt, and XQuery, are proposed to support structure-based and content-based retrieval of XML documents [38–40].

One of the interesting characteristics of XML is document conversion technology. XSLT is used to transform an XML document into a document having different format [41, 42]. Figure 1 shows a situation where XML documents are transformed into HTML5 documents by using XSLT for wireless internet users.

3. Platform Design and Architecture

This paper proposes a system, called IIP (intelligent web digital image information retrieval platform), that can support intelligent image retrieval by utilizing dynamic XML documents. We utilize commercial database systems as storage

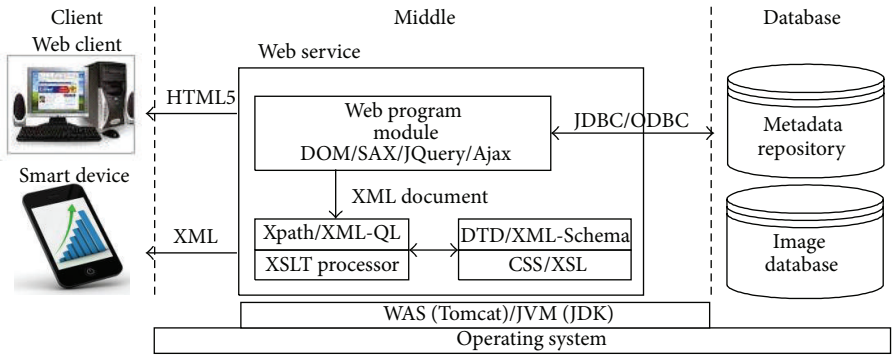


Figure 1: XML-based image metadata service architecture.

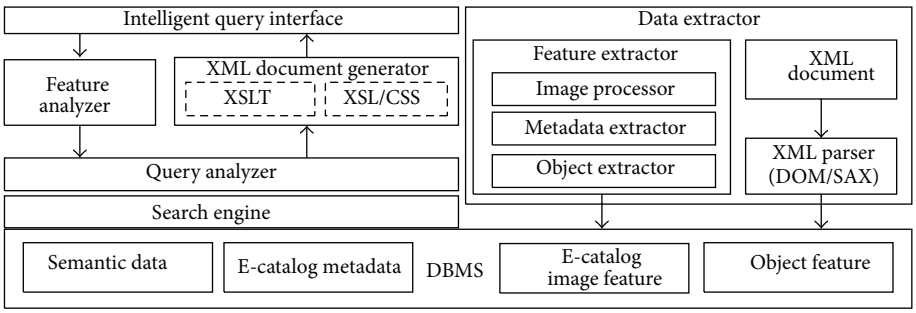


Figure 2: Platform architecture of the IIP.

systems to make our system stable and cost-effective. The system architecture is shown in Figure 2.

Data extractor preprocesses images to extract web digital image feature (global feature) and object feature (local feature). Object features are used to provide content-based retrieval from the viewpoint of component objects contained in images. Image features, object features, semantic metadata, and other meaningful digital image metadata are stored in databases. Content-based queries are submitted through IQI (intelligent query interface) and processed by feature analyzer to extract major features of query objects. The matched results are transformed into HTML5 or XML documents according to the client platforms.

The storage structures are designed by considering mapping relationships with XML documents. Our metadata structure contains global feature, local feature, semantic metadata, and major element of MPEG-7 standard. Figure 3 shows the proposed metadata schema in E-R diagram. Feature vectors for objects in digital images are stored in color, shape, texture, and spatial tables. Semantic information and other meaning metadata are stored in SemanticDS and Metadata InformationDS, respectively. One or more images can share metadata of contained objects by referencing OIDs (object IDs).

4. Web Digital Image Metadata Modeling

In this section, we propose multilevel metadata structures for intelligent digital image information retrieval.

4.1. Multilayer Web Digital Image Metadata Modeling. Web digital image metadata is data for image data. There are two types of basic metadata for images.

(i) *Registration metadata*: image resolution (width, height), color map, compression ratio, and so forth are typical examples of registration metadata. This metadata is required to display and manipulate images. In image files, this information is usually hidden within image headers.

(ii) *Description metadata*: digital image title, caption, keywords, natural language descriptions, and image file names are typical examples of descriptive metadata. This metadata is used to search images, when content-based retrieval operations are not supported.

Registration metadata or description metadata are not enough for content-based searching. We can further define multilayered metadata structures on top of raw image data. They are the following.

(i) *Global feature metadata*: average values or multidimensional vectors representing color, texture, and shape of image are examples of global feature metadata. This metadata is heavily used in current content-based retrieval system.

(ii) *Local feature metadata*: Average values or multi-dimensional vectors representing color, texture, and shape of each objects or regions belonging to a given image are examples of local feature metadata.

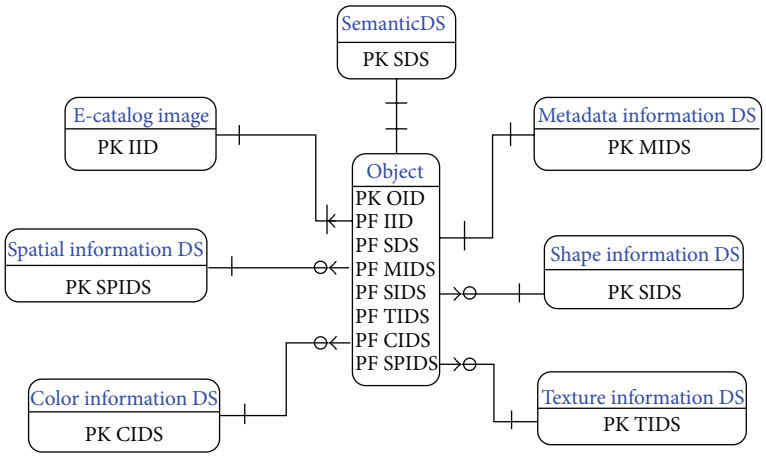


Figure 3: Image metadata schema in E-R diagram.

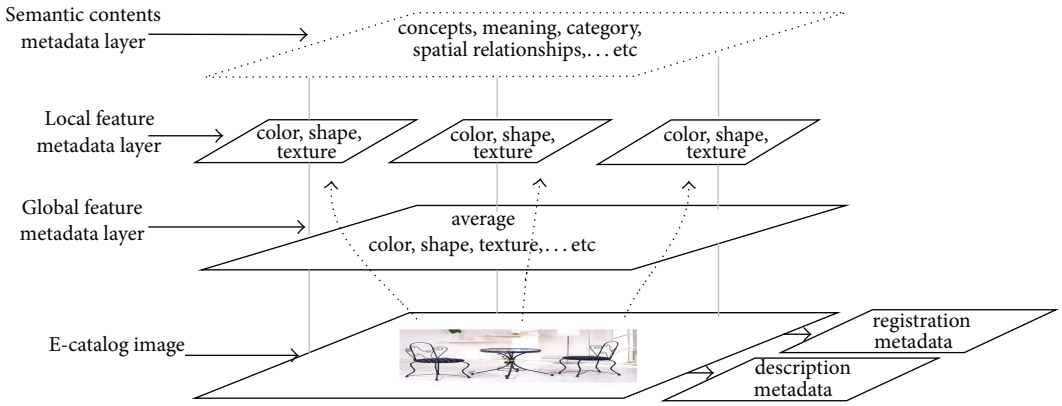


Figure 4: Multilayer metadata modeling.

(iii) *Semantic contents metadata*: subjective feelings and knowledge on images, such as concepts, meaning, category, spatial relationships, or other useful interpretations, are examples of semantic metadata.

Figure 4 explains a processing model of multilayered metadata from a web digital image (or E-catalog image). The bottom layer shows examples of objects contained in images. Global metadata layer contains global features, such as global average color, and it also represents semantic content or knowledge content of a total image. Local metadata layer represents feature vectors of each object belonging to a given image. Semantic content metadata layer represents semantics or knowledge content of each object. For example, a web digital image usually has multiple objects in an image. A feature vector assigned to each object plays an important role in image searching process. In addition, it can be utilized to improve the efficiency of searching process. There have been limitations on user's satisfaction in existing search engines, because they mainly rely on global features only. Figure 5 shows an example of a web catalog image containing multiple objects. The first image of Figure 5 has multiple central objects "chair" and another central objects "table." The second image has central objects "necktie" and "T-shirt." The

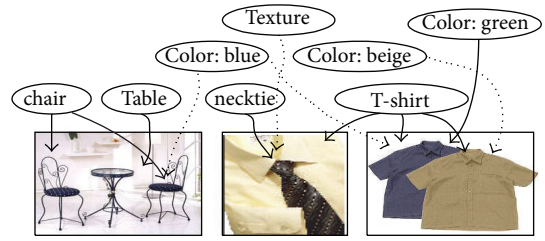


Figure 5: Examples of web e-catalog images.

third image has central object "T-shirt." But, it is easily shown that each has different color. Like this situation, central objects can have different feature vectors, even though their meanings are the same. Vice versa, they can have same feature vectors, while their meanings are different.

4.2. XML Representation of Web Digital Image Metadata. The DTD structure to represent metadata of an image is shown in Figure 6. This DTD structure is focused on the object viewpoint as well as the global image viewpoint [43]. In this design, we also adopted major elements of MPEG-7 standard.

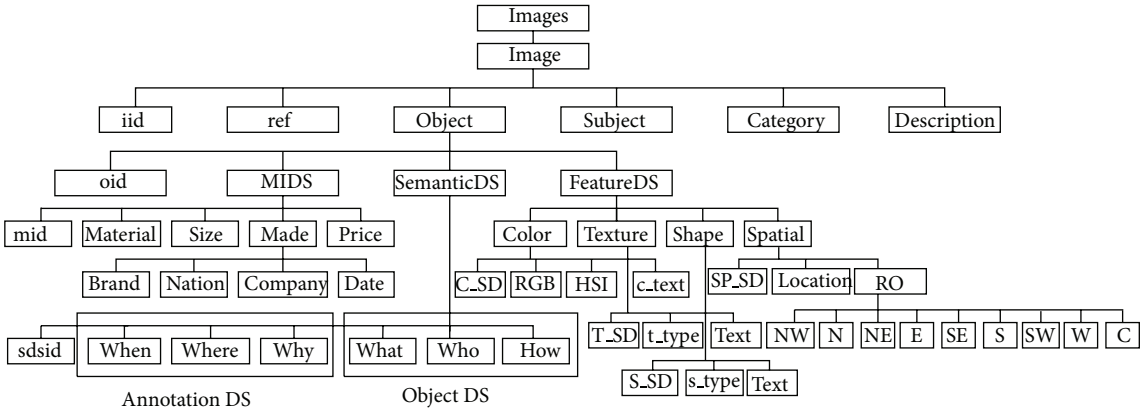


Figure 6: XML DTD structure.

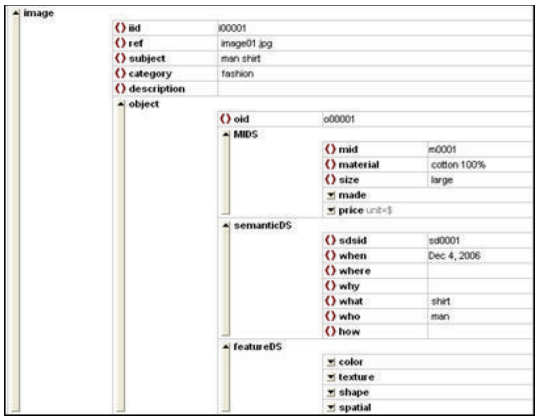


Figure 7: An example of XML document to describe metadata of an e-catalog image.

Figure 7 shows an example of XML document to describe metadata of an image containing multiple objects.

We use XML-Schema to define the form of XML documents for image metadata [44, 45]. We designed an XML-Schema to represent image metadata containing multiple objects. Figure 8 shows a metadata structure of such an image from the viewpoint of elements. Object-1 refers to all the elements, while Object-2 refers to a part of its elements. The proposed XML-Schema model allows reuse of element definition. It also allows definition of patterns or models within elements.

Figure 9 shows a document about XML-Schema in Figure 8. In this way, XML-Schema documents verify effectiveness of XML documents for multiobject images.

Figure 10 shows the section, which defines web digital image metadata information in an XML-Schema document. It also explains a mapping scheme of image metadata part in XML-Schema document into relational databases. A user define type called "madeType" is used in order to define a child of an element in an XML-Schema document. Definition of such parent elements and child elements are mapped to table schemes in relational databases.

5. Prototype Implementation

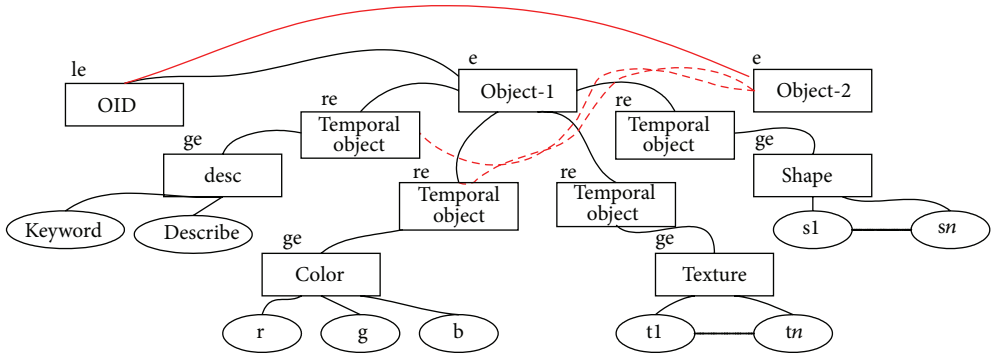
In this section, we describe implementation aspects of intelligent web digital image retrieval platform proposed in this paper. The prototype system is implemented on the Windows Server 2012 with MS-SQL Server 2008. Web client platform is Microsoft Internet Explorer 10.0 and XML Editor Tools. We used languages, such as JQuery, JavaScript, Ajax, DOM (Document Object Model), JAVA, and JSP (Java Server Page) based on SAX (Simple API for XML). Web server is IIS (Internet Information Services) with Tomcat 7 virtual directory server that is supported by MS-SQL server.

5.1. Storing XML Documents in Relational Database System. XML document can be used to provide the platform transparency hiding the difference between systems. The proposed system provides such transparency. We keep XML documents in disk databases. Data extraction procedure from XML documents is explained in Figure 11.

To store data, XML documents are parsed and node structure of XML documents is mapped into tree structure before OpenXML function is called. The stored procedure *sp_xml_preparedocument* validates effectiveness of XML document. After validation, node tree handle, that can extract data from attribute and element, is returned by this stored procedure. After node tree creation is finalized, data is stored in the table to return low set data of XML document.

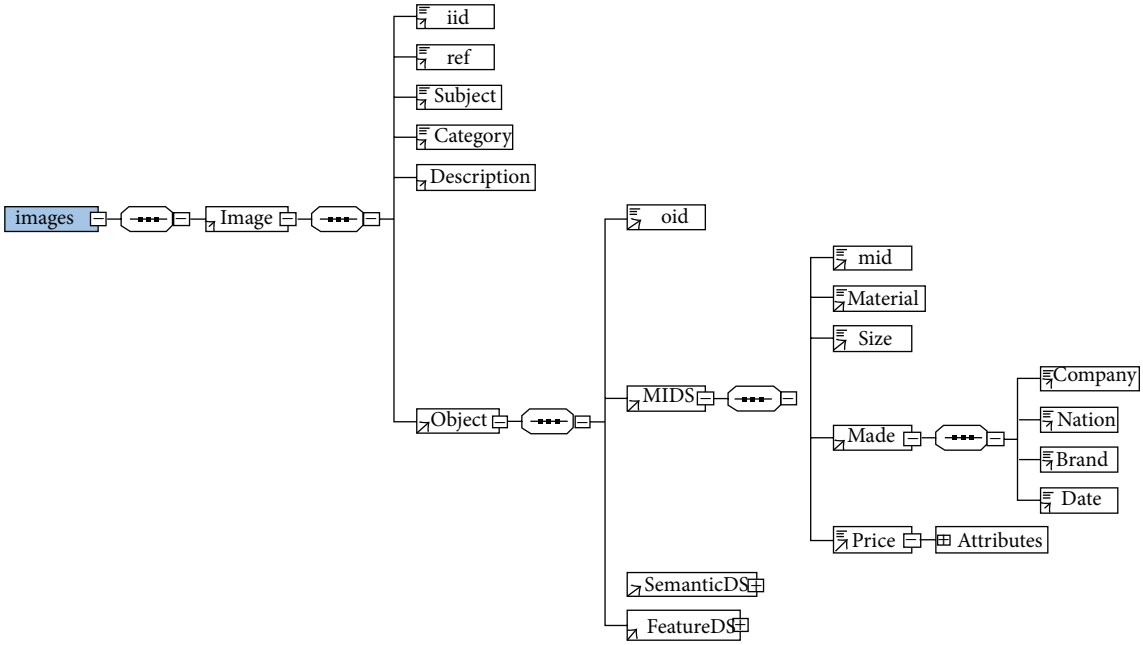
Procedure 1 explains the procedure to store portion of XML document describing image metadata into database tables.

5.2. XML Document Searching. By applying XSL stylesheet into XML data, we can transmit retrieved data in different forms, such as HTML5 documents with CSS3, to web browser-based clients, such as smart phones using App. Before web browser accesses web server, a HTTP header, which contains the required pages, the machine type used by current web user, and various information about web browser, is sent to the web server. A HTTP header in HTTP request packet also contains information on user IP, OS, type of browser, type of document that can be processed in web browser, and

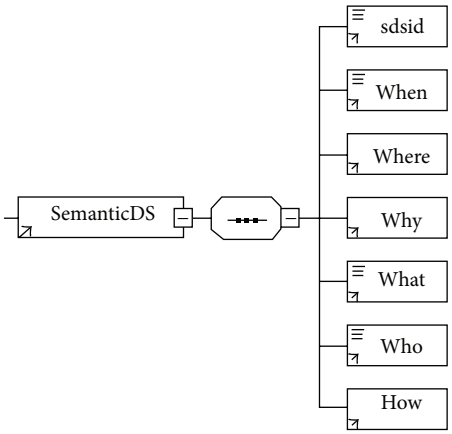


e: element
re: reference element
ge: global element
le: local element

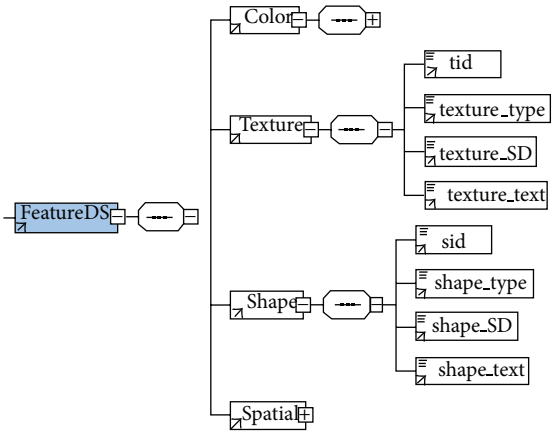
Figure 8: XML-Schema modeling for multiple objects.



(a) Image object and metadata information



(b) Semantic information



(c) Feature information

Figure 9: XML-Schema document.

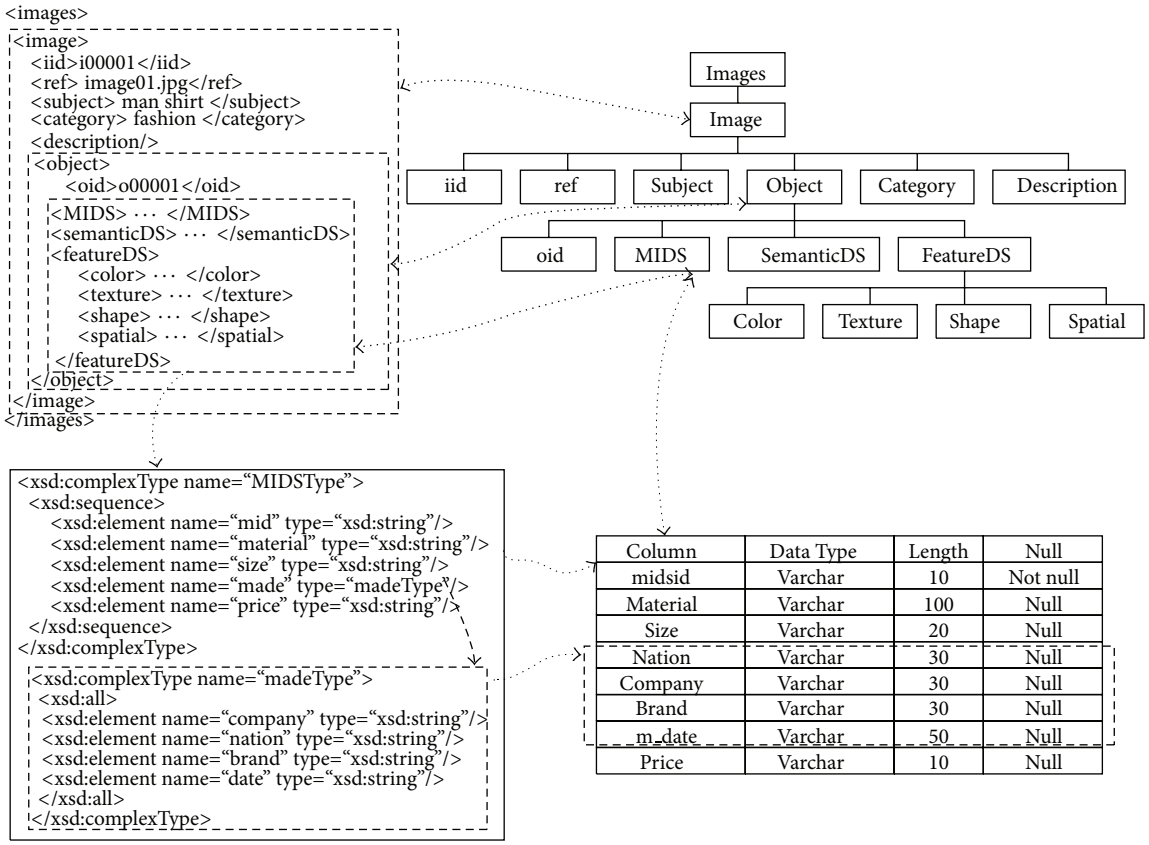


Figure 10: Mapping XML-Schema to relational tables.

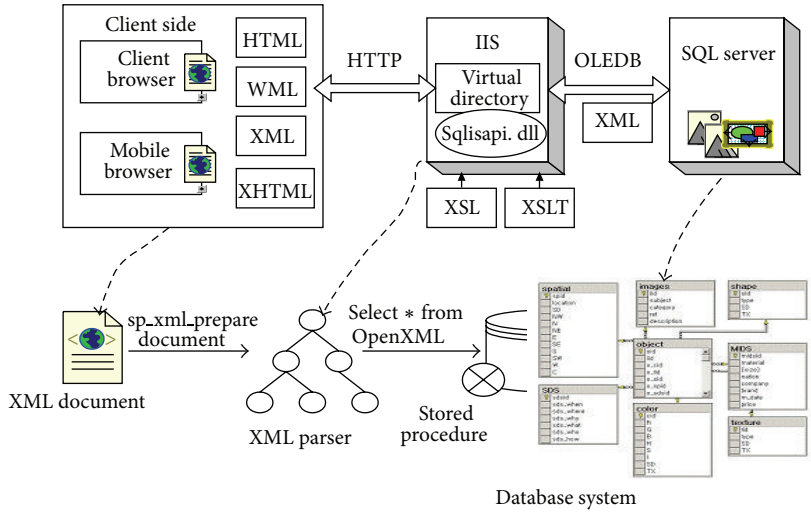


Figure 11: Process to store XML documents.

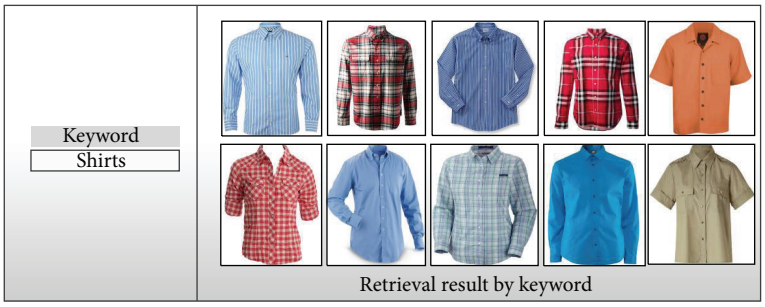
cookie used by login information. We can submit the retrieval results to the smart device after translating them by using XSLT. For this process, HTTP header information is used to identify the type of connected machine. GetHeader method of request object is used to search the header information and "*ACCEPT*" attribute is used to identify the type of connected machine. To identify connected browser, "*USER-AGENT*" attribute is used. Figure 12 shows how image searching is done using XSLT transform process.

6. Conclusions

XML related technologies are evolving rapidly in the Internet environments. Many application systems that utilize merits

```
CREATE PROCEDURE INSERTXMLDOC
AS
DECLARE @xmlDATA VARCHAR(2000)
SET @xmlDATA = '
<?xml version="1.0"? >
<images>
  <image>
   <iid> i00002</iid>
   <subject> samsung cellular phone </subject>
   <category> Phone </category>
   <ref> image02.jpg </ref>
   <description> good cellular phone </description>
  </image>
</images>
'
DECLARE @iTree INTEGER
EXEC sp_xml_preparedocument @iTree OUTPUT, @xmlDATA
INSERT images (iid, subject, category, type, descript)
SELECT iid, subject, category, type, descript
FROM
OPENXML(@iTree, 'images/image', 1)
WITH (iid varchar(10) 'iid',
        subject varchar(100) 'subject',
        category varchar(30) 'category',
        ref varchar(10) 'ref',
        description varchar(500) 'description')
```

Procedure 1: Procedure to store XML documents into RDBMS.



(a) Web digital image retrieval result by keyword

(b) Web digital image retrieval result by hybrid

Figure 12: An example of web digital image searching in IIP.

of XML technologies are recently developed. However, there have been little efforts in adopting XML techniques to realize information retrieval and efficient exchange of multimedia data.

In this paper, we presented web digital image metadata retrieval technique, which adopts XML technology. To support object-based content retrieval on product catalog images containing multiple objects, we described multilevel metadata structures which represent the local features, global features, and semantics of image data. To enable semantic-based and content-based retrieval on such image data, we designed an XML-Schema for the proposed metadata and showed how to represent such metadata using XML documents. We also described how to automatically transform the retrieval results into the forms suitable for the various user environments, such as web browser and smart device, using XSLT. The proposed scheme can be easily implemented on any commercial platforms supporting XML technology.

We are planning to develop an automatic conversion module of multimedia data such as image or video, according to the client platform of end users. There should be further researches to improve user's satisfaction by developing various contents transformation XSLT.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Event-Related Potentials Related to Anxiety in Emotion-Attention Interaction

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To identify neurological characteristics in accordance with anxiety under the interaction between emotion and attention, this study examines major ERP components when participants identify a target number by inhibiting task-irrelevant emotional face distractors. Experiments were conducted once per day at the same time for two days with 19 healthy adult men and women as required to study emotion-attention interaction. In this study, a variety of ERP components such as P100, N200, and P300 during experiment are significant. The amplitude and latency of the N200 component reflect both state and trait anxiety at all positions. This characteristic specially is prominently featured at Cz. Also, the latency of the late P300 component reflects the trait anxiety rather than state anxiety. The result of this study can help our understanding of the neurological responses related to anxiety during attentional control.

1. Introduction

Emotion and attention are essential elements in our everyday life and closely related to each other. Emotion may lead to attention and attention may cause emotion adversely [1]. Although studies of neurological activity related to emotion and neurological responses related to attention have been conducted separately, recent work suggests that emotion and attention are closely related and are involved in interdependent processing [2]. Generally, emotional stimuli command one's attention compared to different types of stimuli, with attentional bias by one's emotional valence. In real life, attention is maintained preferentially by a stimulus with emotional importance compared to a stimulus that is emotionally neutral. For stimuli specially that are potentially threatening, fear and negative emotions are prioritized. This attentional bias is a very normal response; however, individuals with higher anxiety levels more strongly perceive stimuli eliciting anxiety, and they remember these stimuli for longer times compared to individuals with lower anxiety levels [3]. Several studies have insisted that the attention systems of individuals with anxiety are more sensitive stimuli related to threats and are more biased [4, 5]. These studies reported that anxiety disorder may show abnormal attentional bias to a wider range of stimuli and to specific stimuli. The attentional bias of patients with anxiety disorder appears to be faster and stronger [6]. Studies of the effects of anxiety on attentional control by inhibiting distractors analyzed behavior responses to compare cognition performance. Assessed were the saying of color names, reading text, eye movements, response times to specific stimuli, and error rates. Several major factors of emotion-attention appear within 500 msec after a stimulus is presented. Thus, to understand the effects of anxiety on attentional control by inhibiting distractors, measurement data related to an early perception process is required, as are measurements of behavioral responses. The process of information processing of a specific stimulus in the brain can be observed directly because ERP (event-related potential) has high temporal resolution.

According to earlier work related to anxiety, patients with anxiety disorder show greater emotional confusion, attentional bias, and cognitive damage compared to people without such disorders [7–11]. These studies investigated ERP characteristics using IAPS images, emotional faces, and emotional words as the emotional stimuli presented.

However, there are few studies of the effects of anxiety on the efficiency of attentional control. Few studies have examined the effects of anxiety on target identification while inhibiting emotional interfering stimuli to induce interaction between emotion and attention. Thus, the aim of this study is to detect the ERP components related to state and trait anxiety in an environment which requires target identification by inhibiting task-irrelevant emotional distractors, that is, interaction between emotion and attention. These neural characteristics can help us to understand the effects of anxiety on cognition processing and to determine therapy methods and therapy processes related to anxiety disorder.

2. Methods

2.1. Participants and Multisource Interference Task (MSIT). Nineteen right-handed graduates (10 males and 9 females; mean = 30 years of age) from university participated in the study. All participants were free from psychiatric or neurological disorders. All participants provided written informed consent and were compensated for their participation. The study was approved by the Severance Hospital Ethics Review Board. Participants completed the Korean version of the State-Trait Anxiety Inventory (STAI; Spielberger et al. [12]) prior to every session. This study used a modified version of the Multisource Interference Task (MSIT) to induce emotion-attention interaction [13]. All participants participated in two sessions for two days. This task presented three digits around the nose area of an emotional face. Pictures were selected from the FACES 3.3.1 database at the Max Planck Institute for Human Development. The pictures contained a set of images of six facial expressions: neutrality, sadness, disgust, fear, anger, and happiness. Also, the target stimuli consisted of three digits, two matching digits and one nonmatching digit. The one nonmatching digit was the target number. Participants were asked to press the target button using a number keypad, which was created in a laboratory. After taking a 10 min break with their eyes open, the task was presented for 3 minutes to familiarize the participants with the protocol prior to the start of the experiment. As illustrated in Figure 1, during the experiment, 144 fixation crosses and 144 pictures (6 facial types by 24 times) were each presented randomly for a period of 1.5 sec. For each participant, the response time to press the target button was recorded. Errors included incorrect key presses, missed key presses, or response times greater than 1500 ms.

2.2. Electroencephalography (EEG) Recording and Data Reduction. An EEG was continuously recorded for each participant during the task. The EEG was recorded with electrodes positioned according to the international 10–20 method of electrode placement, including the earlobes. The ground electrode was placed on the back of the neck (Iz), whereas the reference electrodes were placed on the right and left ears (A1 + A2). Eye movement artifacts were corrected using the ICA algorithm. All electrode impedances were less than 5 kΩ. The EEG was amplified using a Biopac MP150 TM system, band-pass filtered (0.1–100 Hz), and digitized at a sampling rate of 1000 Hz. The high pass filter of the EEG signal was set to 0.5 Hz, and the low pass filter was set to 100 Hz. A 60 Hz notch filter was in use at all times. ERP amplitudes were obtained by stimulus-locked averaging from 0 ms to 1000 ms after baseline correction. Primary ERP analyses focused on the P100, N200, and P300 components during the task. The P100 (150–250 ms), N200 (250–350 ms), and P300 (350–450 ms) components were compared by analyzing the mean amplitudes and peak latencies at the F3, F4, Cz, and Pz positions after stimulus onset.

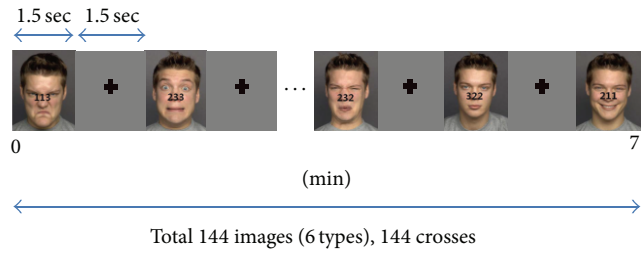

Figure 1: Schematic representation of the experiment design.

To detect the correlation between anxiety and ERP components during MSIT, Pearson's correlation analyses between state/trait anxiety and the P100, N200, and P300 amplitudes and latencies were performed at each position (e.g., F3, F4, Cz, and Pz). Also, to test if there were effects of the face type used as a distractor, covariance analyses were performed on ERP components as a dependent variable. All statistical analyses were carried out using SPSS 14.0 (SPSS Inc., Chicago, IL).

3. Results

3.1. Interrelation between ERP and Anxiety. There were clearly ERP P100, N200, and P300 components at all positions during MSIT. To determine the correlation between the state/trait anxiety (STAI score) and the ERP component during MSIT, Pearson's correlation analyses were conducted. Table 1 shows the correlation scores between P100, N200, and P300 and state/trait anxiety by face type at each position. A minus symbol represents a nonsignificant difference. There were several findings, as follows. (1) The relationship between the N200 component and state/trait anxiety was significant at the F3, F4, and Cz positions. (2) The N200 amplitude at F4 was more closely linked with trait anxiety, whereas both state and trait anxiety were related to the N200 amplitude at F3 and Cz. Finally, (3) the higher the trait anxiety for a negative facial type, the slower the P300 latency at Pz.

3.2. Effect of Anxiety on ERP. We intended to identify whether ERP components were affected by state and/or trait anxiety during MSIT. Also, a covariance analysis was performed to detect if there is a difference in ERP components by face type used as distractor. The ERP P100, N200, and P300 amplitudes and latencies were used as dependent variables and six face types were used as fixed factors. Also, state and trait anxiety were used as covariates. As illustrated in Table 2,

Table 1: Correlation scores among ERP components and anxiety.

Position	ERP components	Facial type	Correlation score (Sig.)	
			State anxiety	Trait anxiety
F3	N200 amplitude	Disgust	.526 (.002)	.626 (.000)
		Fear	.393 (.029)	.463 (.009)
		Smile	.459 (.009)	.430 (.016)
		Neutral	.392 (.009)	.389 (.030)
	N200 latency	Sadness	.447 (.012)	—
		Annoy	−.436 (.014)	—
		Fear	−.488 (.005)	—
		Smile	−.377 (.036)	—
		Sadness	−.401 (.024)	—
F4	N200 amplitude	Annoy	—	.385 (.032)
		Disgust	.480 (.006)	.598 (.000)
		Fear	—	.479 (.006)
		Smile	.443 (.013)	.435 (.014)
		Neutral	—	.393 (.029)
	N200 latency	Fear	−.499 (.004)	—
		Smile	−.369 (.014)	—
		Sadness	−.431 (.016)	—
Cz	N200 amplitude	Annoy	.362 (.045)	.513 (.003)
		Disgust	.524 (.002)	.705 (.000)
		Fear	.449 (.011)	.548 (.001)
		Smile	.547 (.001)	.522 (.003)
		Neutral	—	.415 (.020)
		Sadness	.524 (.002)	.455 (.010)
	N200 latency	Annoy	−.402 (.025)	—
		Fear	−.449 (.011)	—
		Smile	−.404 (.024)	—
		Neutral	−.410 (.022)	—
		Sadness	−.436 (.014)	—
Pz	P300 latency	Annoy	—	.369 (.041)
		Disgust	—	.367 (.042)
		Fear	—	.357 (.049)

both state and trait anxiety had an effect on N200 amplitude and latency at all positions. Also, state anxiety influenced P300 latency at F3 and F4, and it influenced P100 latency at all positions. However, trait anxiety influenced P300 latency at all positions.

4. Conclusions

In this study, the effects of anxiety on cognitive functions were analyzed using ERP in a condition which required emotion-attention interaction. The results can be summarized as follows. First, the P100 (early), N200 (middle), and P300 (late) components appear during the MSIT used in this paper. The tasks consisted of facial expressions as a distractor and three digits as targets. They required cognitive functions such as the sensory processing of facial expressions, target identification, and response decisions. Generally, it is known that the sensory processing of facial expressions is related to early ERP component, that target identification or the response decision is associated with the middle ERP component, and that the high-order cognitive function is related to the late ERP component. This result indicates that there are various ERP components related to emotion-attention interaction during MSIT. Second, the affected ERP amplitude and latency varied depending on the type of anxiety. The N200 amplitude becomes higher with higher state and trait anxiety. The P100 and N200 latencies become faster with higher levels of state anxiety. However, the P300 latency becomes slower with higher levels of trait anxiety. The P300 latency specially was closely related to trait anxiety at all positions. The present study suggests that specific ERP components are related to state anxiety or trait anxiety in an environment with contemporaneous emotional distractors and a target with which it is necessary to detect the target by inhibiting task-irrelevant distractors. Further, these findings may be used

Table 2: Dependence between anxiety and ERP at position.

Position	Dependent variable	Source	Mean square	F	Sig.
F3	P100 latency	State anxiety	.003	25.018	.000
	N200 amplitude	State anxiety	.198	39.021	.000
	N200 latency	State anxiety	.006	33.308	.000
	N200 amplitude	Trait anxiety	.201	39.650	.000
	N200 latency	Trait anxiety	.001	7.710	.006
	P300 amplitude	Trait anxiety	.047	4.341	.039
	P300 latency	Trait anxiety	.008	15.801	.000
F4	P100 latency	State anxiety	.003	21.748	.000
	N200 amplitude	State anxiety	.134	29.031	.000
	N200 latency	State anxiety	.005	25.473	.000
	P300 latency	State anxiety	.003	5.623	.019
	P100 amplitude	Trait anxiety	.036	8.399	.004
	N200 amplitude	Trait anxiety	.161	36.109	.000
	N200 latency	Trait anxiety	.002	12.307	.001
	P300 amplitude	Trait anxiety	.052	5.082	.025
	P300 latency	Trait anxiety	.010	19.356	.000
Cz	P100 amplitude	State anxiety	.012	6.614	.011
	P100 latency	State anxiety	.002	21.041	.000
	N200 amplitude	State anxiety	.120	47.154	.000
	N200 latency	State anxiety	.006	33.838	.000
	P300 latency	State anxiety	.003	4.417	.037
	P100 amplitude	Trait anxiety	.026	14.397	.000
	N200 amplitude	Trait anxiety	.159	68.625	.000
	N200 latency	Trait anxiety	.002	8.320	.004
	P300 amplitude	Trait anxiety	.039	3.628	.058
	P300 latency	Trait anxiety	.011	18.711	.000
Pz	P100 latency	State anxiety	.003	19.097	.000
	N200 amplitude	State anxiety	.032	8.107	.005
	N200 latency	State anxiety	.005	23.365	.000
	N200 amplitude	Trait anxiety	.029	7.148	.008
	N200 latency	Trait anxiety	.003	11.859	.001
	P300 amplitude	Trait anxiety	.032	3.878	.050
	P300 latency	Trait anxiety	.025	22.155	.000

as an index to assess cognition performance for clinical and nonclinical anxiety disorders.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Achieving Fair Spectrum Allocation and Reduced Spectrum Handoff in Wireless Sensor Networks: Modeling via Biobjective Optimization

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This paper considers the problem of centralized spectrum allocations in wireless sensor networks towards the following goals: (1) maximizing fairness, (2) reflecting the priority among sensor data, and (3) avoiding unnecessary spectrum handoff. We cast this problem into a multiobjective mixed integer nonconvex nonlinear programming that is definitely difficult to solve at least globally without any aid of conversion or approximation. To tackle this intractability, we first convexify the original problem using arithmetic-geometric mean approximation and logarithmic change of the decision variables and then deploy weighted Chebyshev norm-based scalarization method in order to collapse the multiobjective problem into a single objective one. Finally, we apply simple rounding method in order to obtain approximate integer solutions. The results obtained from the numerical experiments show that, by adjusting the weight on each objective function, the proposed algorithm allocates spectrum bands fairly with well observing each sensor's priority and reduced spectrum handoffs.

1. Introduction

The demand of allocating and using the radio frequency spectra is rapidly growing due to increasing number of wireless and mobile communication applications, where the industry has reached the limits of current static spectrum allocation. However, actual measurements illustrate that the scarcity is not a result of heavy usage of the spectrum. It is merely due to the inefficiency of the static spectrum allocation pursued by regulators [1].

Dynamic spectrum allocation may resolve this paradox by opening assigned, but sparsely used, spectrum resources to secondary users [2–4]. It exploits underutilized spectrum resources along time or frequency dimension and provides efficient and intensive dynamic spectrum access through the detection of spectrum opportunity and adaptive modulation.

Such dynamic spectrum access schemes can be considered in wireless sensor networks (WSNs) as well. Typical WSNs are composed of resource-constrained sensors responsible for monitoring physical phenomena and reporting to sink points. One of the primary objectives of WSNs is to transmit monitored results timely and concurrently, without using large amount of network resources. The dynamic spectrum access becomes very vital to achieve such timely and concurrent transmissions in WSNs; for instance, in a WSN for real time surveillance system [5, 6] or real time machine-to-machine communications [7], the transmissions of video or image data captured by the sensors require high bandwidth and multiple spectra [8]. Subsequently, the following major principles can be made.

1.1. Fair Allocation of Idle Spectrum Bands. If too many sensors attempt to transmit their data simultaneously, current idle spectrum resources may be insufficient to support all transmissions. In this situation, scarce spectrum resources

should be allocated as fairly as possible; in addition, it is necessary to prioritize the transmissions. This can be achieved by maximizing *proportional fairness* with demanding weights [9]. The main difference between *max-min fairness* and proportional fairness is that the latter is in a sense less fair in terms of the demanding volume assignment but more effective in terms of the total utilization achieved by all participants [10].

1.2. Avoiding Unnecessary Spectrum Handoff. The other primary objective of WSNs is long time functionality. However, dynamic spectrum access leads to supplemental energy consumption at each sensor due to *spectrum handoff*. Spectrum handoff occurs when (1) primary user is detected or (2) current spectrum condition becomes worse; sensors move to the "best matched" available spectrum band. It has been measured that not only decoding and channel estimation but also frequency or timing synchronization consumes a certain amount of power [11]. It means that the more frequent spectrum handoffs lead to the more power consumption. Moreover, due to the latency caused by spectrum sensing, decision, and handoff procedures, quality degradation is inevitable during spectrum handoff [12]. Hence unnecessary spectrum handoff should be eliminated [13, 14].

1.3. Centralized Spectrum Allocation. The problem of dynamic spectrum allocation in cellular network has been studied widely. Various centralized or distributed algorithms are summarized and compared in [15]. In centralized scheme, a centralized authority (e.g., base station or dedicated coordinator) detects and identifies spectrum opportunities and allocates the identified spectra to secondary users in accordance with a predefined policy. All these procedures may be done separately by different entities, that is, detector, identifier, and allocator. Undoubtedly there is an overhead of message exchange since the centralized authority (or allocator) should propagate the results of spectrum allocation into sensor swarm whenever it receives transmission requests. In addition, if sensors are distributed in a wide area, more detectors may be needed.

In distributed scheme, each secondary user competes with one another to access available spectrum resources. Thus each user should have an ability to detect the spectral opportunities and determine an optimal strategy to maximize its benefits (e.g., number of spectrum bands). If the distributed scheme is deployed to WSN, all sensors should have a fully operating cognitive radio. However it is not feasible to implement full features of cognitive radio in such energy-limited sensor nodes. Thus, in a moderate size of WSN, where sensors are not distributed widely, for example, a healthcare system in an intensive care unit, the centralized scheme is preferred to the distributed one.

In this paper, we consider the problem of the centralized spectrum allocations in a WSN of moderate size; that is, all sensors are located within a cell or segment boundary. We assume that sensors, which are going to transmit data immediately or in near future, request spectrum resources to their dedicated coordinator. Then the coordinator allocates each sensor spectrum resources: (1) *as fairly as possible*, (2) *reflecting the priority among sensors*, and (3) *avoiding unnecessary spectrum handoff*. We formulate this problem into a multiobjective, more clearly, bicriteria and biobjective, mixed integer nonlinear nonconvex programming that is, however, known as intractable without any aid of modification or approximation.

Our approach to tackle this problem is summarized as follows. First, we convert the original formulation into a quasiequivalent form that is convex through *arithmetic-geometric mean approximation* and logarithmic change of decision variables. Then we relax the integer constraint, so-called *NLP relaxation*, and collapse the multiobjective optimization problem (MOP) into a single objective one using *scalarization* based on *weighted Chebyshev norm* (also called *supremum* or *infinity norm* [16]) *problem* by which we can maintain the convexity and achieve NLP relaxed solution which satisfies weak Pareto optimality. Finally, we perform simple rounding algorithm on the NLP relaxed solutions in a sequence of steps in order to obtain approximated integer solutions. A noticeable advantage of the proposed approach is that it enables finding fairly good approximated integer solutions within reasonable computation time. It is already proved that approximate solution obtained by the series of arithmetic-geometric mean approximations converges to a point satisfying the Karush-Kuhn-Tucker conditions of the original problem [17]. We estimate the integer solution of rounding method by comparing it with NLP relaxed solution that gives crude upper bounds of the original problem.

The rest of this paper is organized as follows. In Section 2, we present the related work and summarize our main challenges. In Section 3, the problem formulation is given. In Section 4, we describe the procedure of tackling the intractability: convexification, scalarization, and rounding. In Section 5, the results of numerical experiments are described. Finally we conclude this paper in Section 6.

2. Related Work

In [18], the authors consider the deployment of cognitive radio to WSNs and suggest that, by adjusting the constellation size, different data rate can be achieved which will directly influence the power consumption of each node and in turn will affect the lifetime of the whole sensor network. They deploy a distributed spectrum allocation strategy with the assumption that the full functions of cognitive radio, that is, detection, identification, and exploitation of spectrum opportunities, are installed at each sensor node. In [19], the authors apply dynamic spectrum access in the time domain by exploiting white spaces between bursty transmissions of multiaccess communication channels. They mention that if sensors communicate sporadically and at a low rate, it appears reasonable to assume that such systems could efficiently reuse the remaining white spaces.

There are many research literatures that have investigated the centralized spectrum allocation. We list some of them below.

In [20], a scheme to achieve proportional fair rate allocation in multiuser OFDMA system is proposed. The authors deal with fully exclusive subcarrier allocation without any consideration of interference. They apply heuristic algorithm of relatively high complexity.

In [21, 22], the dynamic spectrum allocation among base stations is considered. In [21], the authors apply genetic algorithm in order to allocate spectra while maximizing the spectral efficiency and satisfying each base station's service rate. However, the genetic algorithm is not appropriate for a multiobjective optimization with multiple constraints since if we consider only a population that satisfies all constraints during the entire procedure of the genetic algorithm, the solutions tend to be stagnated at the local optimal [23]. If we use the algorithm without concerning any of the constraints, few solutions subject to all the constraints can be obtained. In [22], the authors propose dynamic spectrum planning that reflects the volume of supported demand at each base station based on its distribution statistics and local interference condition, and they also address a long-term stability and the proportional fairness.

In [24, 25], downlink channel (or subcarrier) allocation problems are considered, and low complex heuristic-based algorithms are proposed in order to solve the problem in reasonable time. The main objectives are to minimize the required transmit power while satisfying the rate requirement and data error rate constraint of each user [24] and maximize the total number of active subcarriers that can be supported to unlicensed users [25], respectively.

In [26], the authors propose an intuitional heuristic algorithm for proportional fair rate allocation. They express the problem using nonlinear convex programming and estimate the heuristic algorithm by comparing its results with the optimal solution.

In [27], the authors model the joint power control and rate allocation problem in a multiuser CDMA system as geometric programming, which can be converted into a convex form easily. They have also considered the proportional fair rate allocations.

In [28], the authors prove that the region of feasible signal-to-inference ratio (SIR) is strictly convex if it has logarithmic scale. As a result, they show that the problem of finding a power vector that maximizes a weighted sum of logarithmic SIR is strictly convex, which coincides with the power control problem of achieving maximal weighted proportional fair SIR among users.

In [29], the authors have considered a game theory based bandwidth allocation mechanism in WiMax environments.

Comparing to the abovementioned related work, our main contributions can be highlighted as follows. We consider the issue of spectrum handoff, which means the problem is formulated as having discrete variables. A separate objective function has been established for the spectrum handoff instead of expressing it as a constraint in order to get several active solutions. (If we include the spectrum handoff in the constraint set, the number of spectrum handoffs will be bounded to a parameter that cannot be tuned during the problem solving in order to achieve reduced spectrum handoffs. Therefore, if the decision maker expects the active improvements in two or more objectives simultaneously by only one-shot problem solving, it is inevitable to model the problem into an MOP [16].) Accordingly, the problem is formulated as a multiobjective mixed integer nonlinear programming (MO-MINLP). Furthermore, convexification, scalarization, and rounding method have been employed to make the problem more tractable.

3. Problem Formulation

We formulate our centralized spectrum allocation problem as an MO-MINLP. Prior to describing the formulation, the following assumptions are made.

(1) Available spectrum resources are expressed as a number of spectrum units, and the bandwidth of each spectrum unit is fixed, for example, subcarrier in OFDM or subband in multiband ultrawide band (UWB).

(2) Each sensor can transmit over noncontiguous frequency bands concurrently [20, 24, 30].

(3) Similar to [26, 27], each receiver sensor declares its desired signal-to-interference noise ratio (SINR). The SINR value reflects a specific required level of bit error rate (BER) since there is an explicit relationship between BER and SINR according to modulation schemes.

(4) All sensors can access entire idle spectrum resources. It means that sensors are distributed within the cell or segment boundary where primary nodes are associated.

(5) Similar to general centralized methods, the detection of spectrum opportunities, identification, and exploitation are always correct, and a dedicated coordinator does all these processes. Furthermore, the dedicated coordinator also lies within the same cell or segment boundary with the sensors.

(6) The process of the spectrum allocation is performed in every start of predefined epoch, where the coordinator detects idle spectrum units and the sensors that requested spectrum resources. The epoch may also start whenever the coordinator receives demands of spectrum units or periodically. Moreover, there is no change in the channel condition within each epoch.

(7) We consider direct communications among only sensors as shown in [31].

(8) Actually, a spectrum handoff occurs at a receiver as well as a transmitter. However, it is impossible to avoid the handoffs in both transmitter and receiver if both were not coupled in the last epoch and currently synchronized with different spectrum units. Hence, in this paper, we consider the spectrum handoff at only a transmitter.

Based on the above assumptions, the MO-MINLP can be described as follows.

Parameters

(i) V: set of sensors that request spectrum units for their transmissions.

(ii) S: set of idle spectrum units.

(iii) L_{is} (binary): it indicates that spectrum unit s was used by sensor i at its previous transmission phase. It means that, currently, sensor i is synchronized with the spectrum unit s. We assume that the sets S and V vary in every transmission epoch. Thus we suppose that the current L reflects the optimal solution of right previous epoch.

(iv) w_i: weight given in accordance with the priority of sensor i. The higher priority a sensor has, the more spectrum units will be allocated. It means that the priority reflects the demand of spectrum units.

(v) $P_i^{\max}$: maximal transmission power available at sensor i.

(vi) $\mathrm{INSR}^{\max}$: $1/\mathrm{SINR}^{\min}$, where $\mathrm{SINR}^{\min}$ is the minimal SINR that corresponds to strict QoS constraint.

(vii) G_{ij}^s: channel gain between sensors i and j over spectrum unit s.

Decision Variables

(i) x_{is} (binary): it indicates that sensor i occupies spectrum unit s.

(ii) p_{is}: transmission power for sensor i in spectrum unit s.

(iii) INSR_{is}: reciprocal of SINR of sensor i in spectrum unit s, defined as

$$\mathrm{INSR}_{is} = \frac{\sum_{j\in V\setminus\{i\}} x_{js}p_{js}G_{jk}^s + \sigma^2}{p_{is}G_{ik}^s}, \tag{1}$$

where σ^2 is noise power.

Objectives. Consider the following:

$$\text{Maximize } f_1 = \sum_{i\in V} w_i \ln\left(\sum_{s\in S} x_{is}\right) \tag{2}$$

$$\text{Maximize } f_2 = \sum_{s\in S}\sum_{i\in V} L_{is}x_{is} \tag{3}$$

s.t.

$$c_1 : x_{is}\mathrm{INSR}_{is} \le \mathrm{INSR}_i^{\max} \quad \forall i \in V,\ s \in S, \tag{4}$$

$$c_2 : \sum_{s\in S} x_{is}p_{is} \le P_i^{\max} \quad \forall i \in V, \tag{5}$$

$$c_3 : x_{is} \in \{0,1\} \quad \forall i \in V,\ s \in S. \tag{6}$$

According to the definition in [20], a resource allocation scheme P is proportionally fair if and only if, for any other feasible allocation scheme M, we have

$$P = \arg\max_M \sum_{i\in V} w_i \ln R_i^{(M)}, \tag{7}$$

where w_i is the weight of user i and $R_i^{(M)}$ is the average resource of user i by an allocation scheme M. The weight reflects each user's priority to the proportional fair allocation as well (i.e., we give more resources to the user with higher priority) [9, 28].

Therefore, by maximizing f_1, we can achieve maximal proportional fairness in terms of the number of spectrum units allocated to each sensor and reflect the priority of each sensor simultaneously.

By maximizing f_2, we can let each sensor keep holding the spectrum units used in the previous transmission epoch. Constraint c_1 indicates that there is a corresponding SINR threshold that determines whether or not packet transmission is successful. That is, if c_1 is satisfied then the intended receiver can receive the packet correctly, and, otherwise, the packet is lost [32]. Constraint c_2 indicates that no sensor can use more transmission power than its maximal available transmission power.

Unlike the general fair "rate" allocation schemes [20, 26, 27], we consider fair "spectrum unit" allocations here due to the following reason: as shown in constraint c_2, each sensor is guaranteed to achieve SINR at least larger than $\mathrm{SINR}^{\min}$. Since the SINR values directly correspond to the rates and if it is guaranteed that each sensor achieves the exact same SINR as $\mathrm{SINR}^{\min}$, the fair spectrum unit allocation will yield the "coarse-grained" fair rate allocation.

However, the problem is intractable due to its nonconvexity and discrete variables. For this reason, we manipulate the objective functions and apply a series of approximations.

Henceforth, we denote the single objective optimization problem with only the objective function f_1 and the constraints as $\Omega(f_1)$ and the one with only f_2 and the constraints as $\Omega(f_2)$, respectively. In addition, we denote the problem by both the objectives and the constraints as $\Omega(f_1, f_2)$.

4. Tackling the Intractability

We begin the convexification process with relaxing the integer constraint; that is, we drop (6).

4.1. Convexification of $\Omega(f_1)$ and $\Omega(f_2)$

4.1.1. Convexification of $\Omega(f_1)$. We convert the original function f_1 into an equivalent log-sum-exp function form that is proved to be convex [17, 27, 33] by defining $\beta_{is} = \ln(x_{is})$ and $\gamma_{is} = \ln(p_{is})$ for all $i \in V$ and $s \in S$, where $-\infty \le \beta_{is} \le 0$ and $-\infty \le \gamma_{is} \le \ln(P_i^{\max})$. Then $\Omega(f_1)$ is reformulated as follows.

Objective. Consider the following:

$$\text{Maximize } f_1^* = \sum_{i\in V} w_i \ln\left(\sum_{s\in S} e^{\beta_{is}}\right) \tag{8}$$

Step 1. Generate initial feasible solution vectors $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$.
Step 2. For all $i \in V$ and $s \in S$, evaluate α_{is} with the initial vectors $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$ using (11).
Step 3. Condense the objective function f_1^* into $Cv(f_1^*)$.
Step 4. Solve the resulting NLP.
Step 5. Terminate the kth loop if $|f_1^*(k) - f_1^*(k-1)| \le \omega$. Otherwise go to Step 2 with solution vectors $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$ obtained at Step 4.

Algorithm 1: Condensation algorithm.

s.t.

$$Cv(c_1) : \ln\left(\sum_{j\in V\setminus\{i\}}\begin{pmatrix} e^{(\beta_{is}+\beta_{js}+\gamma_{js}-\gamma_{is})}G_{jk}^s\left(G_{ik}^s\right)^{-1}\left(\mathrm{INSR}_i^{\max}\right)^{-1} \\ +e^{(\beta_{is}-\gamma_{is})}\sigma^2\left(G_{ik}^s\right)^{-1}\left(\mathrm{INSR}_i^{\max}\right)^{-1}\end{pmatrix}\right) \le 0$$

$$\forall i \in V, \quad s \in S,$$

$$Cv(c_2) : \ln\left(\sum_{s\in S} e^{(\beta_{is}+\gamma_{is})}\left(P_i^{\max}\right)^{-1}\right) \le 0 \quad \forall i \in V. \tag{9}$$

Nonetheless the reformulated one is not a convex optimization [33]. Therefore, we deploy arithmetic-geometric mean approximation (in geometric programming, arithmetic-geometric mean approximation is used for condensing a posynomial function into a monomial function; therefore it is called also *local monomial approximation* [34]) [17, 34] as

$$\sum_{s\in S} e^{\beta_{is}} \ge \prod_{s\in S}\left(\frac{e^{\beta_{is}}}{\alpha_{is}}\right)^{\alpha_{is}}, \tag{10}$$

and the inequality becomes an equality if

$$\alpha_{is} = \frac{e^{\beta_{is}}}{\sum_{s\in S} e^{\beta_{is}}}, \quad \forall i \in V,\ s \in S. \tag{11}$$

Then the objective is condensed as

$$\begin{aligned}\text{Maximize}\, Cv\left(f_1^*\right) &= \sum_{i\in V} w_i \ln\left(\prod_{s\in S}\left(\frac{e^{\beta_{is}}}{\alpha_{is}}\right)^{\alpha_{is}}\right) \\ &= \sum_{i\in V} w_i \sum_{s\in S}\alpha_{is}\left(\beta_{is} - \ln\alpha_{is}\right),\end{aligned} \tag{12}$$

which becomes affine, and the optimization problem can be solved by condensation algorithm, Algorithm 1 [17].

As condensing the objective function f_1^* into $Cv(f_1^*)$ always yields underestimated solutions, each NLP in the condensation iteration loop tries to improve the accuracy of the approximation to a particular maximum in the original feasible region. In addition, the algorithm is convergent and always produces the approximate solution that satisfies the Karush-Kuhn-Tucker conditions of the original problem [17].

4.1.2. Convexification of $\Omega(f_2)$. As done in the convexification of $\Omega(f_1)$, we let $\beta_{is} = \ln(x_{is})$ and $\gamma_{is} = \ln(p_{is})$ for all $i \in V$ and $s \in S$, where $-\infty \le \beta_{is} \le 0$ and $-\infty \le \gamma_{is} \le \ln(P_i^{\max})$. Then f_2 is converted into a convex form:

$$\text{Minimize}\, Cv\left(f_2\right) = \sum_{s\in S}\sum_{i\in V} L_{is} e^{-\beta_{is}}. \tag{13}$$

The above formulation makes β_{is} close to 0, where $L_{is} = 1$ in order to minimize its value. Thus we can derive the same results as the ones obtained by maximizing f_2.

4.2. Scalarization of the Multiobjective Optimization Problem. For solving MOPs, one of the most widespread approaches is scalarization, where MOPs are replaced by suitable scalar optimization (i.e., single objective optimization) problems involving possibly some additional parameters and constraints. With the help of the scalar problem, not only can one optimal solution of the multiobjective optimization problem be found but also approximations of the whole solution set can be generated by a variation of the parameters. In this paper, we are interested in maintaining the convexity of the scalarized problem as well as guaranteeing weak Pareto optimality at least by minimizing the distance between ideal solutions (i.e., Pareto Frontier) and feasible objective region. To this end, we deploy a scalarization method based on weighted Chebyshev norm problem [16].

We consider an MOP with a vector of decision variables $\mathbf{x}$ and a vector of objective functions $\mathbf{f}(\mathbf{x}) = [f_1(\mathbf{x}), \ldots, f_r(\mathbf{x})]^T$ as follows.

Objectives. Consider the following:

$$\text{Minimize}\ f_m(\mathbf{x}), \quad m = 1, \ldots, r \tag{14}$$

s.t.

$$h_l(\mathbf{x}) \le 0, \quad l = 1, \ldots, t. \tag{15}$$

To begin with, we normalize each mth objective function f_m to be given 0 as the minimum value and 1 as the maximum value as follows:

$$f_{mn}(\mathbf{x}) = \frac{f_m(\mathbf{x}) - f_m(\mathbf{x}_m^*)}{f_{mw}(\mathbf{x}) - f_m(\mathbf{x}_m^*)}, \tag{16}$$

where $f_{mw} = \max_{j=1,\ldots,r} f_j(\mathbf{x}_j^*)$ and $\mathbf{x}_j^*$ is the optimal design vector obtained when only f_j is minimized. That is, the distance between its optimal solution and worst solution normalizes each objective function. Then the weighted Chebyshev norm problem is defined by additional variable z as follows.

Objectives. Consider the following:

$$\text{Minimize } z, \tag{17}$$

s.t.

$$\begin{aligned} \delta_m f_{mn}(\mathbf{x}) &\le z, \quad \forall m = 1, \ldots, r, \\ h_l(\mathbf{x}) &\le 0, \quad l = 1, \ldots, t, \end{aligned} \tag{18}$$

where $\delta_m > 0$ is the weight of f_m (notice that the δ_m expresses relative weight rather than absolute weight). By solving this scalarized problem, the maximal distance between the ideal solution ($f_m(\mathbf{x}_m^*)$) and the feasible objective region ($f_m(\mathbf{x})$) is minimized. (This scalarized problem corresponds to the problem that achieves the weighted fairness between objective values within min-max (i.e., supremum, and also called maxminimization) criterion. There is another scalarization approach that considers the proportional fairness between objective values [35]. But it fails to maintain the convexity of original problem.) It is easy to check that the weighted Chebyshev norm problem maintains the convexity if the original problems are convex; that is, all $f_m(\mathbf{x})$ and $h_l(\mathbf{x})$ are convex. Definitely, as an objective function has higher weight, it is liable to be emphasized relatively more than others.

We can envisage the linear combination of objective functions, such as $\delta_1 f_1 + \delta_1 f_1$, in order to scalarize the multiobjective optimization problem. However the Chebyshev normalization is preferred to the linear combination due to the following reasons.

(1) The unit and scale of each objective are different: one expresses the number of handoffs and the other one expresses fairness value in terms of the number of spectrum. So we need to normalize the scales of the objectives.

(2) The linear combination does not guarantee the balance (fairness) between the two objectives. Surely, adjusting the weight of each objective may yield the balanced outcome but it is quite difficult to find the adequate weights. However, our approach yields balanced output without the weight values (i.e., delta_1 and delta_2). Then we can control the weight of each objective by adjusting the weight values. Surely, this approach is more straightforward.

If we denote $Cv(f_1^*)$ and $Cv(f_2)$ by g_1 and g_2, respectively, the problem $\Omega(f_1, f_2)$ is converted into a single objective optimization problem by Chebyshev norm problem.

Objectives. Consider the following:

$$\text{Minimize } z, \tag{19}$$

s.t.

$$\begin{aligned} Cv(c_1) &: \ln\left(\left(\sum_{j\in V\setminus\{i\}} \left(e^{(\beta_{is}+\beta_{js}+\gamma_{js}-\gamma_{is})} G_{jk}^s + e^{(\beta_{is}-\gamma_{is})}\sigma^2\right)\right) (G_{ik}^s)^{-1} (\mathrm{INSR}_i^{\max})^{-1}\right) \le 0 \quad \forall i \in V, \quad s \in S, \\ Cv(c_2) &: \ln\left(\sum_{s\in S} e^{(\beta_{is}+\gamma_{is})} (P_i^{\max})^{-1}\right) \le 0 \quad \forall i \in V, \\ c_4 &: \delta_1 \times \left(\frac{-\sum_{i\in V} w_i \sum_{s\in S} \alpha_{is}(\beta_{is} - \ln\alpha_{is}) - g_1^*}{g_{1w} - g_1^*}\right) \le z, \\ c_5 &: \delta_2 \times \left(\frac{\ln\left(\sum_{s\in S}\sum_{i\in V} L_{is} e^{-\beta_{is}}\right) - g_2^*}{g_{2w} - g_2^*}\right) \le z, \end{aligned} \tag{20}$$

where g_1^* is the optimal value when only $Cv(f_1^*)$ is minimized and g_2^* is the optimal value when only $Cv(f_2)$ is minimized. Similarly, g_{1w} is the value of $Cv(f_1^*)$ when only $Cv(f_2)$ is minimized and g_{2w} is the value of $Cv(f_2)$ when only $Cv(f_1^*)$ is minimized. We apply α_{is} obtained when solving $\Omega(f_1)$ by condensation. Therefore, prior to solving $\Omega(f_1, f_2)$, we should solve $\Omega(f_1)$ and $\Omega(f_2)$, respectively; the global solution of all these problems can be computed using a general NLP solving method such as *interior point method* [36].

4.3. Rounding Algorithm. Regardless of convexity and linearity, a problem with integer constraints is in general very hard to solve. In this paper, we apply a simple rounding method introduced in [34] for finding approximated integer solutions of $\Omega(f_1, f_2)$. We also use the rounding method to find the integer solutions of $\Omega(f_1)$ and $\Omega(f_2)$ for the purpose of evaluation. The algorithm of the rounding method is given as Algorithm 2.

In Step 2, we first solve NLP relaxed and convexified problems. In Step 3, rounding is performed with rounding distance ξ, which is the distance between x_{is} and its nearest integer. Then the feasibility is checked with the rounded solutions in Step 3. If the rounded solutions are not feasible, we reduce the rounding distance by ξ (i.e., the rounding condition is made stricter) and perform the rounding and feasibility check again. Otherwise, in Step 5, we compute integer solutions using the original objective functions for the problem $\Omega(f_1)$ and $\Omega(f_2)$, and, for the problem $\Omega(f_1, f_2)$, we compute weighted summation of two normalized objective values since a single-valued metric is required for determining whether the iteration should proceed further or not. In Step 6, we update the best solution until the current iteration and fix the rounded solutions as parameters for the

Step 1. $best\_sol := 0$;
$old\_sol := 0$;
$\boldsymbol{\beta} := \{\beta_{is} : \forall i \in V \text{ and } \forall s \in S\}$;
$\boldsymbol{\gamma} := \{\gamma_{is} : \forall i \in V \text{ and } \forall s \in S\}$;
Step 2. Solve NLP relaxed problem with the solution vectors $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$;
Step 3. **for each** $\beta_{is} \in \boldsymbol{\beta}$ **begin**
  if $(|\exp[\beta_{is}] - 1.0| \le \xi)$
    $x_{is} := 1$;
  else
    $x_{is} := 0$;
end
Step 4. Check the feasibility of the original problem with the rounded $\mathbf{x}$.
  if not feasible **begin**
    $\xi := \xi - \zeta$;
  goto Step 3;
end
Step 5. Compute integer solution *int_sol* of each objective function:
(1) For $\Omega(f_1)$,

$$int\_sol := f_1 = \sum_{i \in V} w_i \ln\left(\sum_{s \in S} x_{is}\right);$$

(2) For $\Omega(f_2)$,

$$int\_sol := f_2 = \sum_{s \in S} \sum_{i \in V} L_{is} x_{is};$$

(3) For $\Omega(f_1, f_2)$,

$$int\_sol := \delta_1 f_{1n} + \delta_2 f_{2n}$$

where f_{1n} and f_{2n} are normalized f_1 and f_2 respectively computed by (16).
Step 6. **if** $(int\_sol > best\_sol)$
  $best\_sol := int\_sol$;
Step 7. **for each** $\beta_{is} \in \boldsymbol{\beta}$ **begin**
  if $(x_{is} = 1)$
    $\boldsymbol{\beta} := \boldsymbol{\beta} - \{\beta_{is}\}$; // if $x_{is} = 1$, fix β_{is} as a parameter for next rounding iteration.
End
Step 8. **if** $(|old\_sol - int\_sol| < \varepsilon)$
  Terminate the algorithm;
else
  $old\_sol := int\_sol$;
goto Step 2;

Algorithm 2: Rounding algorithm.

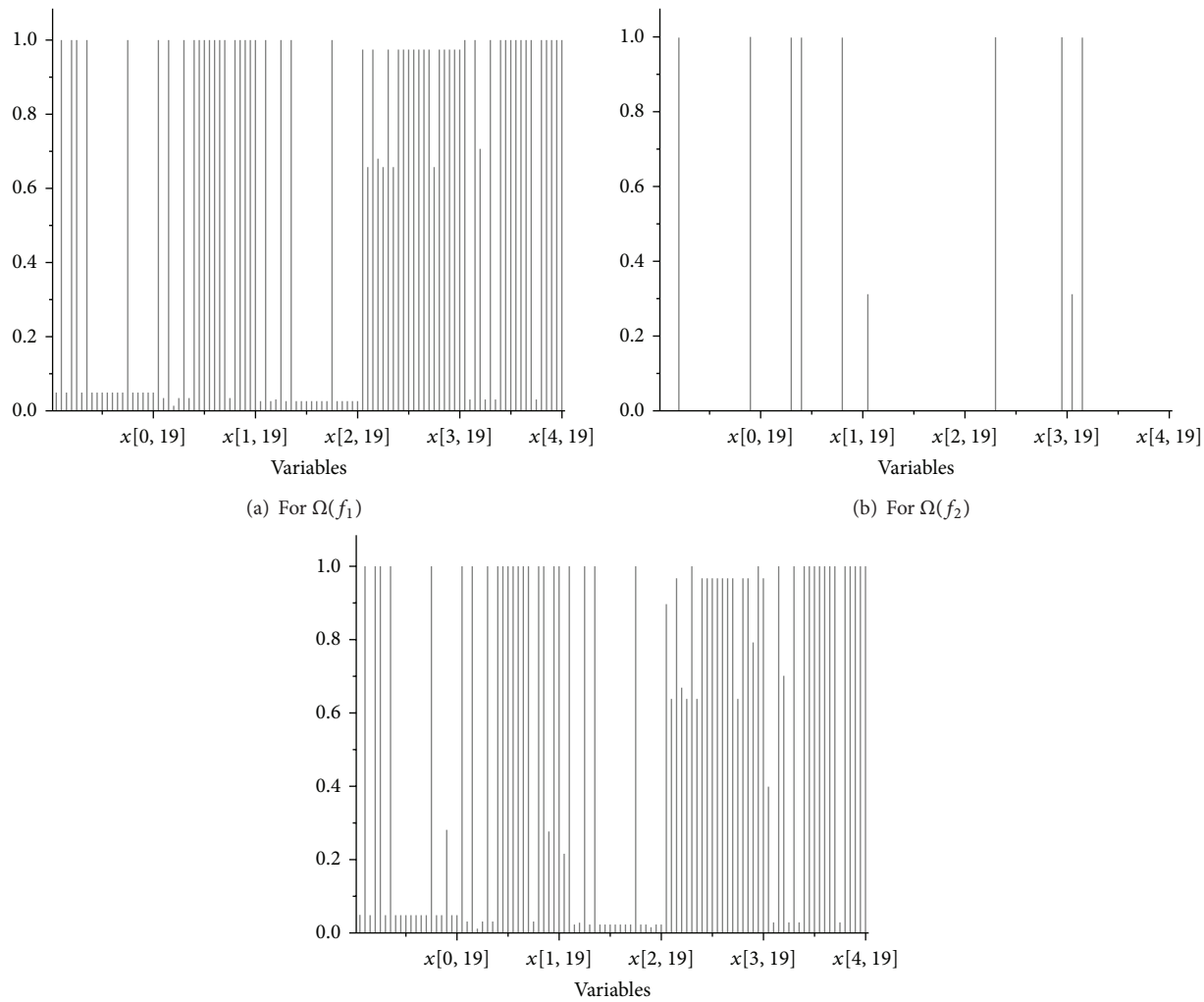
next iteration in Step 7. Finally, if we conclude that the integer solutions are converged within a certain level, we terminate the rounding algorithm.

Although the rounding algorithm is quite efficient and easy to implement, it often produces infeasible solutions. To make matters even worse, it is extremely difficult to fit the rounded solutions into the constraints. However we observe that it works well for our problems since all the objective functions and constraints involve exponential function, which means that the NLP solver has a tendency to produce the variables bisected into very small or large values in order to seek the maximum (or minimum) results. To illustrate this phenomenon, we choose a small sensor topology where 5 sensors are distributed uniformly in a 20 m × 20 m square and assume 20 idle spectrum units. We compute the NLP relaxed solutions of all the problems and plot them in Figure 1 where, for the problem $\Omega(f_1)$, the outputs of the condensation algorithm are plotted.

As shown in Figure 1, we observe that some variables are quite close to 1 and a few of them are exactly 1, while some other variables are relatively very small. As a result, we can parameterize these bisected variables easily in the first rounding, which enables the next rounding to begin with reduced set of variables. In addition, we observe that the variables converge to feasible integer solutions within a few rounding iterations. We show this result in the next section.

5. Numerical Experiments

For the experiments, we consider a sensor field of 100 m × 100 m rectangular area where 15 sensors are uniformly distributed and assume that all the sensors request transmissions. We generate each sensor's transmission target randomly, which may result in one-to-many or many-to-one communications as well as one-to-one. The other main experimental parameters are listed in Table 1. We use



(a) For $\Omega(f_1)$

(b) For $\Omega(f_2)$

(c) For $\Omega(f_1, f_2)$

Figure 1: NLP relaxed solutions of variable x_{is} for all $i \in V$ and $s \in S$, for $\Omega(f_1)$. We plot the solution after the condensation.

the channel gain modeled as $G_{ij} = K_0 \cdot 10^{\delta ij/10} \cdot (d_{ij})^{-\nu}$, where δ_{ij} is random Gaussian variables with zero mean and standard deviation equal to 6 dB, $K_0 = 10^3$ that captures system and transmission effects such as antenna gain, and carrier frequency, and d_{ij} is the distance between sensors i and j, and υ is the power falloff factor. We let $\upsilon = 3$. We implement all the experimental codes in C language using IPOPT [36] library that implements an NLP solver with interior point method. To illustrate that the condensation algorithm yields well converged NLP solution of the problem $\Omega(f_1)$ we measure the function value, $Cv(f_1^*)$—defined in (14)—on each iteration of the condensation procedure, and Figure 2 shows the measured results. As shown in the graphs, we can observe that the function value $Cv(f_1^*)$ converges to a stationary value as the condensation proceeds.

Table 2 lists the number of rounding iterations required to arrive at the given termination condition $\varepsilon = 10^{-8}$. It is observed that the rounding algorithm converges to the termination condition within a few iterations as a rule except in the case of the problem $\Omega(f_2)$.

We evaluate the multiobjective solutions determined by the scalarization method by comparing with each single objective solution. Not only the integer solutions but also the NLP relaxed solutions are compared with varying the weight on each objective function, that is, δ_1 and δ_2. The results are plotted in Figure 3; we perform this evaluation with 60 different random channels that satisfy 95% maximum allowable error of 0.1 dB and plot the average values over those samples. The label of X-axis on each graph corresponds to the pair of weight on each objective function; from left to right, while δ_1 increases, δ_2 decreases. In the legend, "INT-f1" and "INT-f2" are associated with the integer optimal values of the corresponding objective functions determined by the scalarization method and rounding algorithm; "NLP-f1" and "NLP-f2" correspond to the NLP relaxed optimal values of the corresponding objective functions obtained after

Table 1: Main experimental parameters.

Experimental parameter	Value
Number of sensors (n)	15
Number of idle spectrum units	60
Weight (w_i)	Assign a uniform random variable between 1 and 20 on each sensor
L_{hold}	0.1
σ^2	10^{-10} W
$P_i^{\max}$	1 mW for all $i \in V$
$\text{INSR}_i^{\max}$	−10 dB
Termination condition for the condensation algorithm ω	0.1
Initial rounding distance (ξ)	0.9999
Rounding distance decrement (ξ)	0.0001
Termination condition for the rounding algorithm (ε)	10^{-8} for $\Omega(f_1)$ and $\Omega(f_1, f_2)$ and 0 for $\Omega(f_2)$

L_{hold}: probability that each sensor holds a spectrum unit at its previous transmission phase.

Table 2: The number of rounding iterations required for the integer solutions with the termination condition ε.

Problem	$N = 15$
$\Omega(f_1)$	2
$\Omega(f_2)$	9
$\Omega(f_1, f_2)$ ($\delta_1 = 0.001, \delta_2 = 1.0$)	2
$\Omega(f_1, f_2)$ ($\delta_1 = 0.01, \delta_2 = 1.0$)	2
$\Omega(f_1, f_2)$ ($\delta_1 = 0.1, \delta_2 = 1.0$)	3
$\Omega(f_1, f_2)$ ($\delta_1 = 1.0, \delta_2 = 1.0$)	3
$\Omega(f_1, f_2)$ ($\delta_1 = 1.0, \delta_2 = 0.1$)	2
$\Omega(f_1, f_2)$ ($\delta_1 = 1.0, \delta_2 = 0.01$)	2
$\Omega(f_1, f_2)$ ($\delta_1 = 1.0, \delta_2 = 0.001$)	2

the scalarization. In addition, the items with "$*$" in the legend correspond to the single objective solutions. In this graph, we plot the NLP relaxed and integer solutions using the original objective functions, f_1 and f_2 in (2) and (3), respectively. The remarkable results are as follows: (i) both the NLP relaxed solutions and integer solutions of f_1 and f_2 in $\Omega(f_1, f_2)$ are apparently proportional to their respective weights; (ii) the solutions determined by the scalarization method are strictly bounded to each of the single objective solutions; (iii) the integer solutions are very close to the NLP relaxed solutions with the factor of less than 2 for both of the objective functions [14].

Next we measure how fairly the spectrum resources are allocated. To show this, we compute *fairness index* using (21) and plot it in Figure 4. Fairness index is widely used metric that measures the level of fairness. As it is close to 1, the allocation is fairer. We also plot spectrum utilization using (22) in order to show how well the spectrum resources are

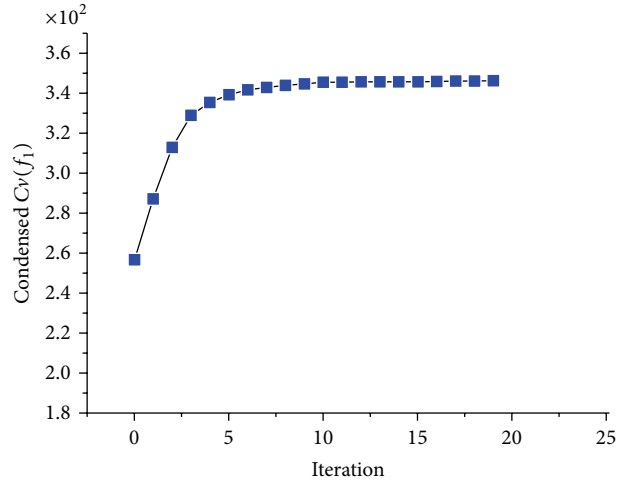


Figure 2: The transition of the function value $Cv(f_1^*)$ as the condensation proceeds.

utilized. We plot the average results obtained over 60 different random channels:

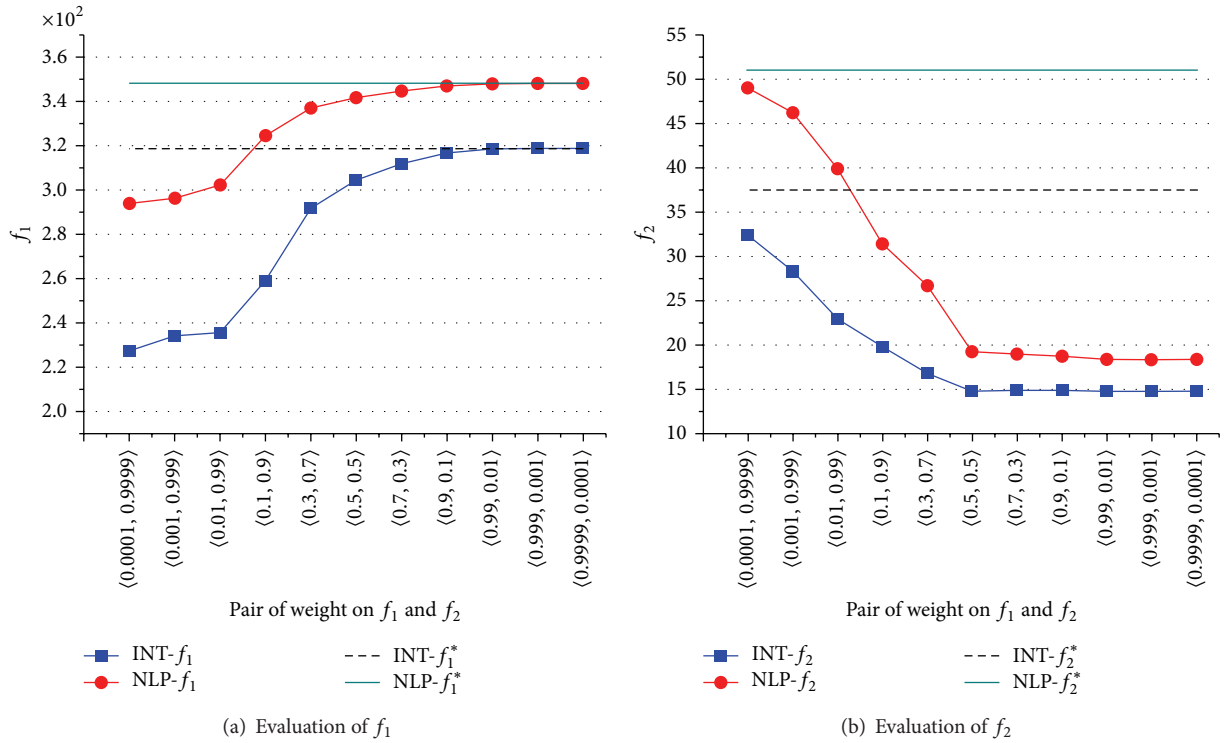
$$\text{FI} = \frac{\left(\sum_{i\in V}\left(\left(\sum_{s\in S} x_{is}\right)/w_i\right)\right)^2}{\left[n\sum_{i\in V}\left(\left(\sum_{s\in S} x_{is}\right)/w_i\right)^2\right]} \tag{21}$$

$$\text{SU} = \sum_{i\in V}\sum_{s\in S}\frac{x_{is}}{|S|}, \tag{22}$$

where n is the number of sensors.

Figure 4 shows that, as the weight on f_1 increases, also the fairness index increases generally. It is observed that the highest fairness index is yielded on $\langle 0.5, 0.5\rangle$, and as f_1 gets more weight, it decreases slightly, which conforms to the attribute of the proportional fairness; if there are unallocated resources, maximal proportional fairness is achieved as allocating them despite of suffering the deterioration in the fairness index. On the other hand, maximal max-min (or min-max) or strict fairness does not endure such deterioration.

To supplement with the evaluation results, we measure both integer and NLP relaxed function values of f_1, f_1^*, f_2, and f_2^* and fairness index and spectrum utilization under different SINR constraints (i.e., with varying $\text{INSR}^{\max}$ in constraint c_1) fixing the weight pair as <0.5, 0.5>. We also measure the average value over 60 sampled random channels in these experiments. The results are plotted in Figure 5. As expected, it is noticed that all the function values and spectrum utilization increase as $\text{INSR}^{\max}$ increases. With regard to the fairness, the highest fairness index is yielded when $\text{INSR}^{\max} = -10$ dB, and it is measured as 0.8563129; when $\text{INSR}^{\max} = -7$ dB, the fairness index is measured as 0.8515264 that is lower than the case of $\text{INSR}^{\max} = -10$ dB. However, both the integer and NLP relaxed values of f_1 are higher when $\text{INSR}^{\max} = -7$ dB due to the higher spectrum utilization, which complies with the attribute of the proportional fairness, less fairness but higher utilization.



(a) Evaluation of f_1 (b) Evaluation of f_2

FIGURE 3: Evaluation of f_1 and f_2 achieved by the scalarization method. The label of X-axis on each graph corresponds to the pair of weight on each objective function, $\langle \delta_1, \delta_2 \rangle$. The integer solutions obtained by the rounding algorithm are also evaluated by comparing them to the NLP relaxed solutions.

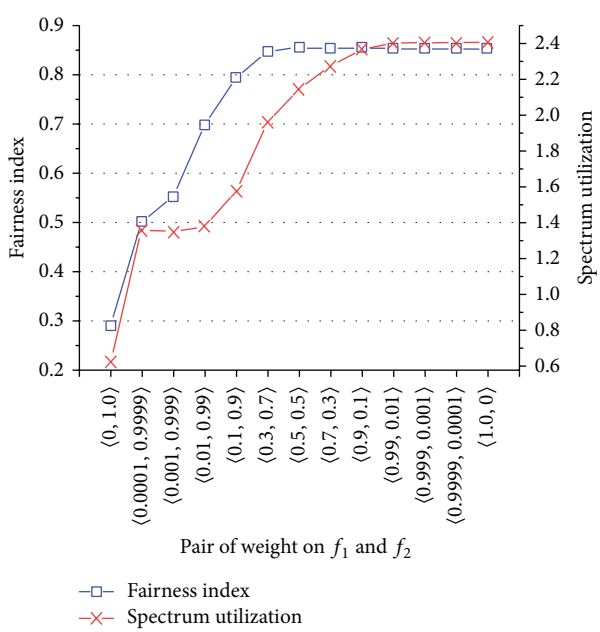


FIGURE 4: Fairness index and spectrum utilization according to the weights.

6. Conclusions

This paper deals with the problem of spectrum allocation in resource-constrained wireless sensor networks with the following goals: (1) *maximizing fairness*, (2) *reflecting the priority among sensor data*, and (3) *avoiding unnecessary spectrum handoff*. The first two goals are achieved by maximizing weighted proportional fairness. Therefore the problem has been formulated as an optimization with two different objective functions: multiobjective optimization. The multiobjective optimization is an indispensable tool for decision making if the benefit of a decision does not depend only on one object. The object is further mapped by one scalar-valued function, that is, scalarization. We deploy the scalarization method based on Chebyshev norm problem in order to maintain the convexity of the objective functions and constraints. Prior to applying the scalarization, the original objective functions are convexified by the arithmetic-geometric mean approximation and logarithmic change of decision variables. Also, all the constraints are transformed into log-sum-exp function form that is strictly convex. Furthermore, in order to find the good approximate integer solutions, a simple rounding algorithm is used, which is quite efficient due to the exponential feature of the problem. The numerical experiments illustrate the efficiency of the proposed solutions including the condensation and rounding algorithm. Furthermore, by the discreet adjustment of the weight on each objective function, the proposed algorithm performs well in achieving the balanced multiobjective solutions. Finally, it is illustrated that, given the weight of each sensor, the algorithm allocates spectrum units fairly as well as yielding high spectrum utilizations when f_1 has relatively higher weight than f_2.

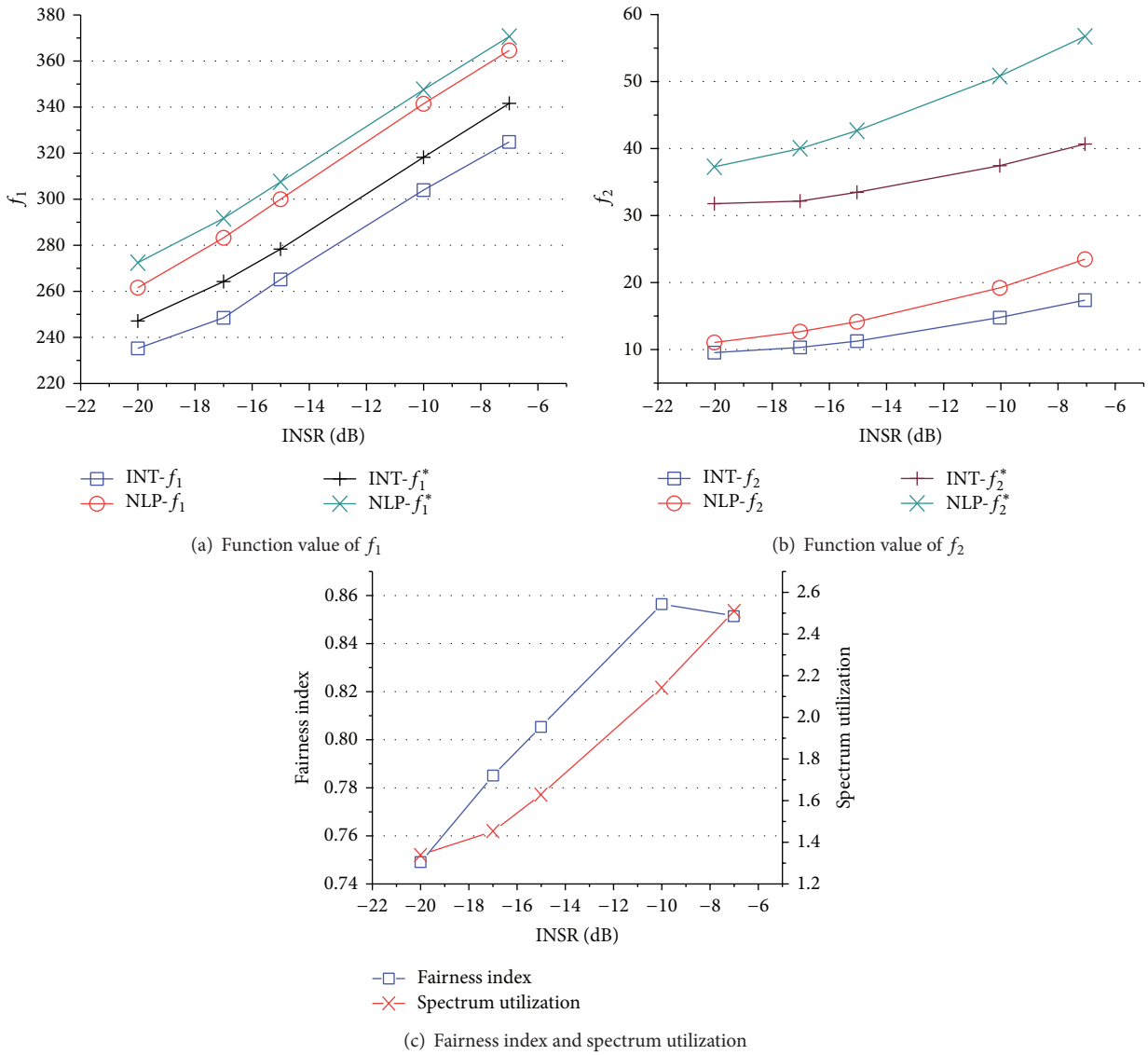


FIGURE 5: Evaluation of function values of f_1 and f_2, fairness index, and spectrum utilization according to various $\text{INSR}^{\max}$. The "INSR" on X-axis indicates $\text{INSR}^{\max}$. We measure both integer and NLP relaxed function values of f_1, f_2, f_1^*, and f_2^*.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Computer Aided Modeling and Analysis of Five-Phase PMBLDC Motor Drive for Low Power High Torque Application

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In order to achieve high torque at low power with high efficiency, a new five-phase permanent magnet brushless DC (PMBLDC) motor design was analyzed and optimized. A similar three-phase motor having the same D/L ratio (inner diameter (D) and length of the stator (L)) is compared for maximum torque and torque ripple of the designed five-phase PMBLDC motor. Maxwell software was used to build finite element simulation model of the motor. The internal complicated magnetic field distribution and dynamic performance simulation were obtained in different positions. No load and load characteristics of the five-phase PMBLDC motor were simulated, and the power consumption of materials was computed. The conformity of the final simulation results indicates that this method can be used to provide a theoretical basis for further optimal design of this new type of motor with its drive so as to improve the starting torque and reduce torque ripple of the motor.

1. Introduction

Brushless DC (BLDC) motor drives are stabbing the market in various consumer and industrial systems, such as home appliances, computer peripherals, automotive applications, and aerospace motor drives in recent years because of their high efficiency, silent operation, high reliability, and low maintenance requirement [1–3]. Power electronic converters are being utilized for variable speed drives. The power rating of the converter should meet the required level for the machine and driven load. However, the converter ratings cannot be increased over a certain range due to the limitation on the power rating of semiconductor devices.

The advent of inverter fed motor drives also removed the limits of the number of motor phases. This fact made it possible to design machine with more than three phases and brought about the increasing investigation and applications of five-phase motor drives. Five-phase motor drives have many advantages over the traditional three-phase motor drives such as reducing the amplitude and increasing the frequency of torque pulsation, reducing the stator current per phase without increasing the voltage per phase, and increasing the reliability and power density. The purpose of using such systems is mainly for achieving higher power level, reducing torque pulsation, increasing the torque density, and improving the reliability.

There are many performance analysis methods for the five-phase PMBLD motor such as direct circuit motor analysis, state equation simulation, analytic method of electromagnetic field, and electromagnetic finite element numerical method. In particular, finite element numerical analysis method is widely used in the analysis and calculation of various electrical equipment, and it can consider the circumstance of nonlinear ferromagnetic materials, as well as the changes of parameters in motor [4]. The electromagnetic analysis software of Maxwell was adopted to emulate the basic characteristics and the starting process of the five-phase PMBLD motor. The results show that this method is lucid and feasible.

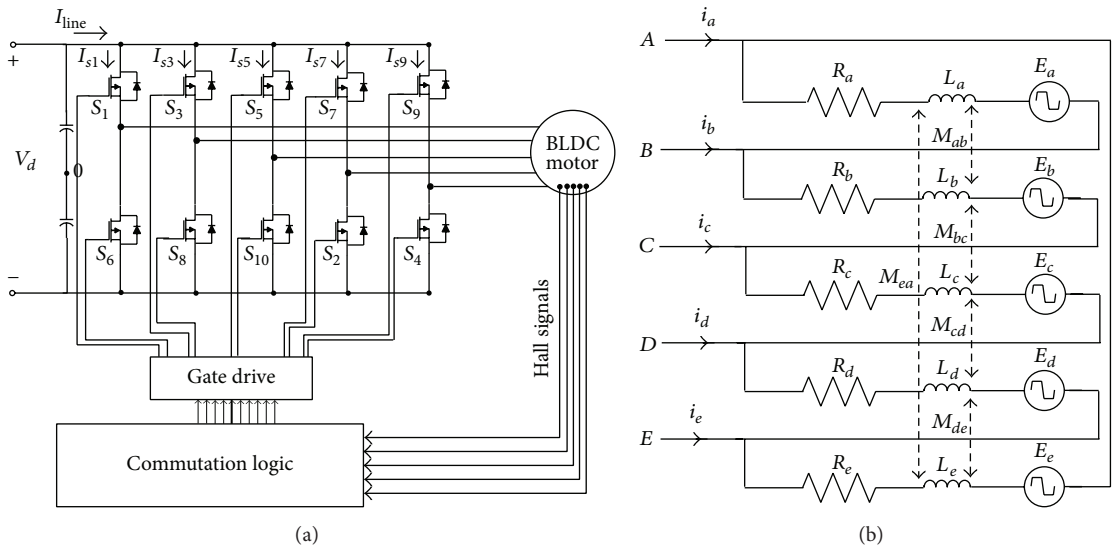


Figure 1: (a) Five-phase MOSFET inverter based BLDC motor drive; (b) equivalent electrical motor model.

2. Mathematical Model of Five-Phase PMBLDC Motor

The mathematical model of five-phase PMBLDC motor is given in [5]. Figures 1(a) and 1(b) show the overall system configuration of the five-phase BLDC motor drive and its equivalent electrical motor model. The PWM inverter topology is a ten-switch voltage source configuration with constant DC-link voltage (V_d). The following assumption is made for simplification of the analysis to come.

(1) The motor is not saturated.

(2) Stator resistances of all the windings are equal, and self- and mutual inductances are constant.

(3) Power semiconductor devices in the inverter are ideal.

(4) Iron losses are negligible.

Among the above-mentioned assumptions, the iron loss can be approximated using empirical equations, and the dynamic characteristics of the switching devices need to be considered for the investigation of transient state behavior. Under the above assumptions, the five-phase PMBLDC motor can be represented as

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{cd} \\ V_{de} \\ V_{ea} \end{bmatrix} = R_S \begin{bmatrix} i_a - i_b \\ i_b - i_c \\ i_c - i_d \\ i_d - i_e \\ i_e - i_a \end{bmatrix} + L_S \frac{d}{dt} \begin{bmatrix} i_a - i_b \\ i_b - i_c \\ i_c - i_d \\ i_d - i_e \\ i_e - i_a \end{bmatrix} + \begin{bmatrix} E_a - E_b \\ E_b - E_c \\ E_c - E_d \\ E_d - E_e \\ E_e - E_a \end{bmatrix}, \tag{1}$$

where L_a, L_b, L_c, L_d, $L_e = L$ are the self-inductance of each phase in Henry, M_{ab}, M_{bc}, M_{cd}, M_{de}, $M_{ea} = M$ are the mutual inductances between the five phases in Henry, $L_S = L - M$ is the equivalent inductances per phase in Henry, R_a, R_b, R_c, R_d, $R_e = R$ are the per phase resistance of the five phases in Ohm, $R_S = 2R$ is the effective line to line resistance in ohm, V_{ab}, V_{bc}, V_{cd}, V_{de}, and V_{ea} are the line to line voltages in volt, i_a, i_b, i_c, i_d, and i_e are the phase currents of each coil in ampere, and E_a, E_b, E_c, E_d, and E_e are trapezoidal back EMF in volt. The performance analysis of five-phase PMBLD motor is based on time domain mathematical model. Under these voltages, currents and total power loss of input power and output power are shown in (3)-(4). The output mechanical torque is shown as (6), and motor efficiency is shown as (7):

$$P_{\text{in}} = \frac{1}{T} \int_0^T \left(V_a i_a + V_b i_b + V_c i_c + V_d i_d + V_e i_e \right) dt, \tag{2}$$

$$\begin{gathered} V_{ab} = V_a; \quad V_{bc} = V_b; \quad V_{cd} = V_c; \\ V_{de} = V_d; \quad V_{ea} = V_e, \end{gathered} \tag{3}$$

$$\begin{gathered} i_{ab} = \sqrt{1.38} i_a; \quad i_{bc} = \sqrt{1.38} i_b; \quad i_{cd} = \sqrt{1.38} i_c; \\ i_{de} = \sqrt{1.38} i_d; \quad i_{ea} = \sqrt{1.38} i_e, \end{gathered} \tag{4}$$

$$P_{\text{out}} = P_{\text{in}} - P_{\text{loss}}, \tag{5}$$

$$T_{\text{out}} = \frac{P_{\text{out}}}{\omega_r}, \tag{6}$$

$$\eta_t = \frac{P_{\text{out}}}{P_{\text{in}}} * 100\%. \tag{7}$$

3. Two-Dimensional Finite Element Model of Five-Phase PMBLDC Motor

The model of five-phase PMBLDC motor was established and analyzed by Maxwell software. Initially, according to the requirement of the control system, the main technical parameters of the five-phase PMBLDC motor could be optimized, as given in Table 1. Then, two-dimensional finite

Table 1: Geometric motor parameters.

Parameter	Value
Rated voltage in volts	24
Rated speed in rpm	3000
Number of pole	4
Stator outer diameter in mm	55.2
Rotor outer diameter in mm	45.6
Rated power in watt	210
Number of phases	5
Slot number	10
Stator inner diameter in mm	46.6
Air gap in mm	0.5

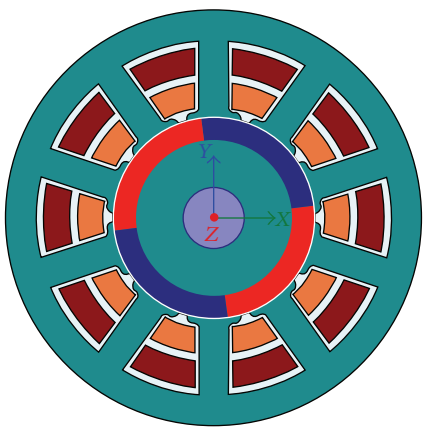


Figure 2: Two-dimensional finite element model (time: 0.02 s).

element model was established by Maxwell 2D software, as shown in Figure 2. Finally, the no load and load of five-phase PMBLDC motor were computed and analyzed in the transient state module of Maxwell 2D.

3.1. Control Circuit System. To make an accurate simulation analysis, Maxwell circuit editor module in Ansoft software was adopted to establish the external circuit model and complete finite element model along with the geometric model that was established [6]. Control circuit system for driving the five-phase PMBLDC motor is mainly made up of the model of drive circuit and power converter. Control circuit system is shown in Figure 3. Here, V138 and V139 are voltage sources; D140 to D151, D169 to D172, and D175 to D178 are diodes; S_52 to S_57, S_67, S_68, S_73, and S_74 are voltage controlled switches; V120 to V125 and V218 to V221 are pulse voltage sources; IVC1 to IVC10 are ammeters; MOSFET power controllable switches and diodes were applied to simulate controllable switch silicon devices in the actual five-phase PMBLDC motor circuit. Diodes which are in series with the controllable switch are used to set the actual voltage drop. Besides, ten diodes are required as freewheeling diodes. Pulse voltage sources, ground voltage meters, and resistors are applied to the drive circuit model.

3.2. Finite Element Grid System. To ensure the accuracy of magnetic circuit calculation and magnetic field analysis, finite element grid was subdivided by manual mode. The magnetic field was divided into 22146 units by the methods of inside selection and surface approximation [7–9]. The overall subdivision model and the partial enlargement model are shown in Figures 4(a) and 4(b), respectively. The subdivision of finite element grid is relatively uniformly distributed on the whole, and the grid subdivision has a higher density in the field where the magnetic field is relatively strong and changes greatly, such as the air gap part. Therefore, the subdivision of finite element grid can reach the desired effect and satisfy the accuracy of finite element calculation.

4. Results and Discussions

A two-dimensional transient simulation model of five-phase PMBLDC motor and a three-phase PMBLDC motor from Crouzet were modeled in the Maxwell 2D module software, namely, Ansoft Maxwell. Both motors' rating is tabulated in Table 2.

4.1. Analysis of Electromagnetic Field. The distributions of magnetic line are made at the transient simulation time of 23 ms five-phase motor and three-phase motor. Similarly, the magnetic flux density for five-phase and three-phase motors is done at 21 ms and 25 ms. The results are shown in Figures 5 and 6, respectively. From the figure, the red magnetic line of force is positive extreme, the blue magnetic line of force is negative extreme, and there are flux leakages in stator slots too. Figure 5 gives the distribution of magnetic lines in three- and five-phase PMBDLDC motor. It is seen that in a three phase motor the area occupied by the flux lines for a given angular position are more creating more stranded losses, but in case of five phase motor the area occupied by the flux lines for a given angular position is less, thereby generating low stranded losses. Moreover, the distribution of flux around the air gap periphery is nonuniform in a three-phase motor compared to five-phase PMBLDC motor. Figure 6 shows that the magnetic flux density is higher in the yoke part of the stator and exhibits deeper color which results from permanent magnets. Through analyzing the distribution of magnetic line, the specific distribution of internal complicated magnetic field in the motor and magnetic saturate situation of each part can be ascertained in this work so as to provide a better theoretical basis to optimize the structure of the motor.

4.2. Analysis of Dynamic Processes. The induced voltages of the no load and load of five-phase PMBLDC motor are carried on simulation computation, and the simulation results were compared, as shown in Figure 7 (with load) and Figure 9 (with no load). Figure 7 shows that the load voltage distribution of stator winding induced EMF is nonsinusoidal

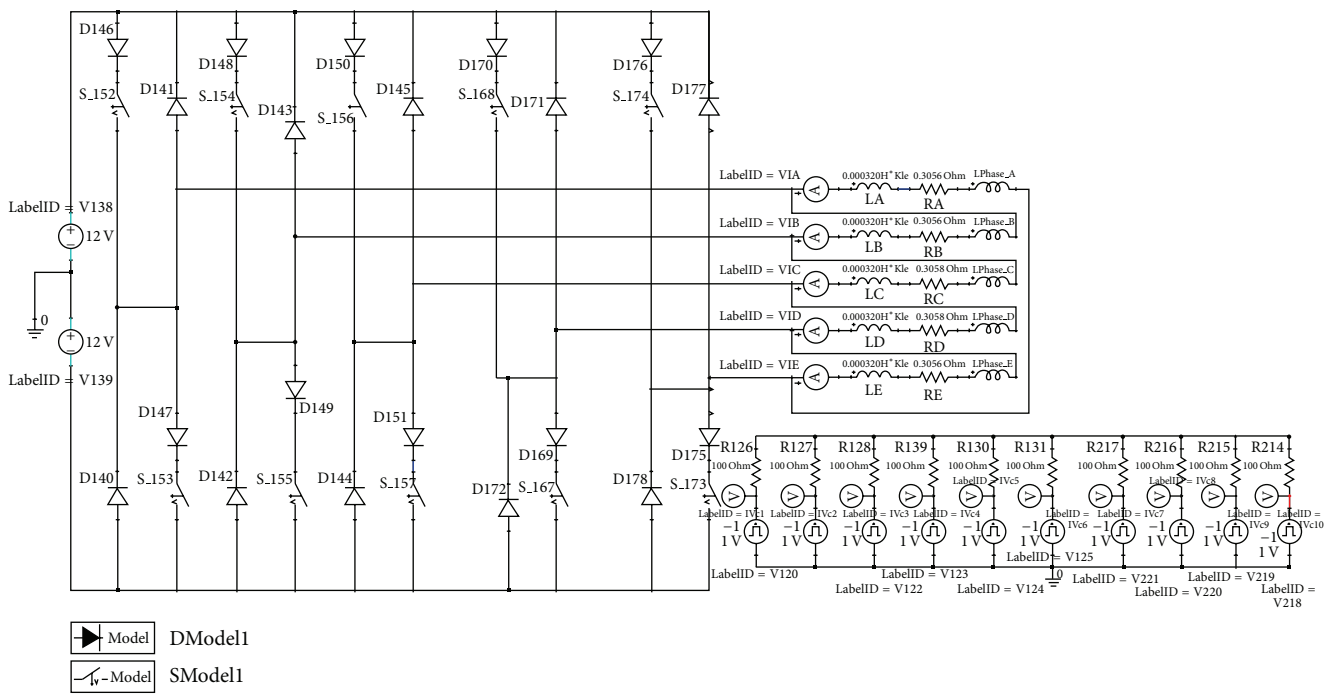


Figure 3: Control circuit system.

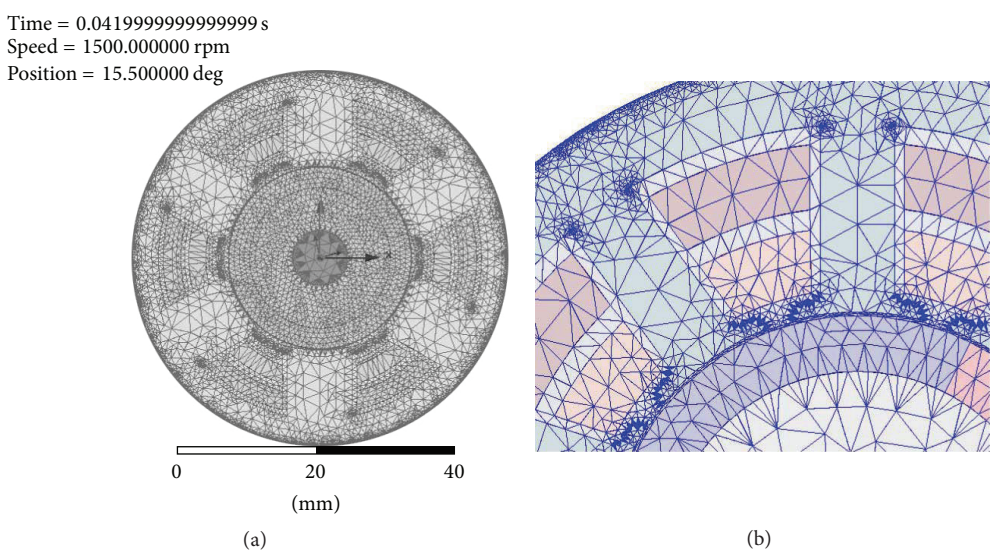


Figure 4: Grid subdivision model (time = 41.9 ms, 15.5 deg displacement). (a) Overall subdivision model. (b) Partial enlargement model.

and approximately less than no load voltage. It gives the dynamic behavior of induced voltage for a five-phase motor when loaded with 0.2 Nm load torque at 1500 rpm. It is seen that the speed of the motor drops from 1500 rpm to 628 rpm within 33 ms. The induced EMF also drops from 8.2 V to 6.1 V peak voltage for phase winding A.

4.3. Waveforms and Discussions. The waveforms for both the three-phase and five-phase motors running at 1500 rpm are shown for no load conditions. Figure 8 shows the phase currents of the motors indicating that the current drawn by the five-phase motor is 1.2 times that of three-phase motor. Similarly, Figure 9 infers that the five-phase induced voltage is 1.4 times that of three-phase motor. Figure 10 shows that the five-phase flux linkage is 1.3 times that of the three-phase motor. The motoring torque of the two motors is shown in Figure 11. It is seen that the torque of the three-phase motor varies from 0.18 to 1.7 Nm over one cycle producing an average torque of 0.94 Nm. In case of five-phase motor,

Table 2: Three-phase and five-phase motors.

Parameters	Symbol	Type of motor	
		3-phase Crouzet PMBLDC motor	5-phase developed PMBLDC motor
Rated power	P	160 W	210 W
Rated input voltage	V_{in}	24 V	24 V
Rated armature current	I_a	8.8 Amps	10.8
Rated speed	N	3500 rpm	1400
Resistance (per phase)	R_a	0.12 Ω	0.305 Ω
Armature inductance	L_a	0.6 mH	0.32 mH
Magnetic flux linkage	Φ	0.02 Wb	0.02 Wb
Number of poles	P	4	4
Rated torque	T	0.4365 Nm	1.5 Nm
Winding configuration		Delta	Delta

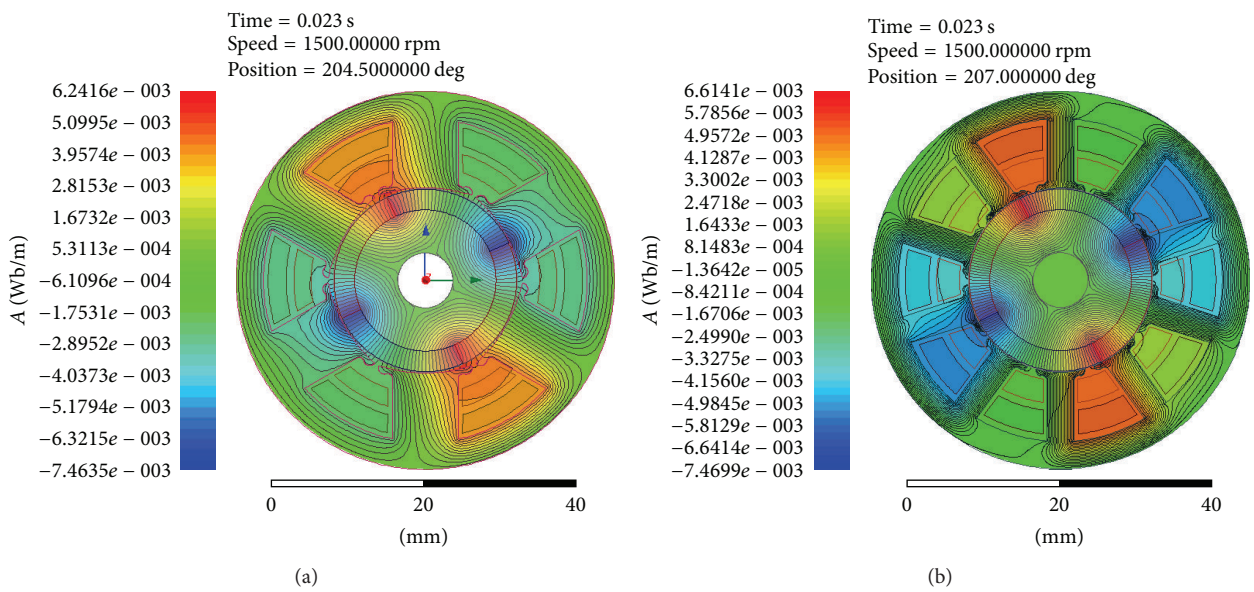


Figure 5: Distribution of magnetic lines in three- and five-phase motors.

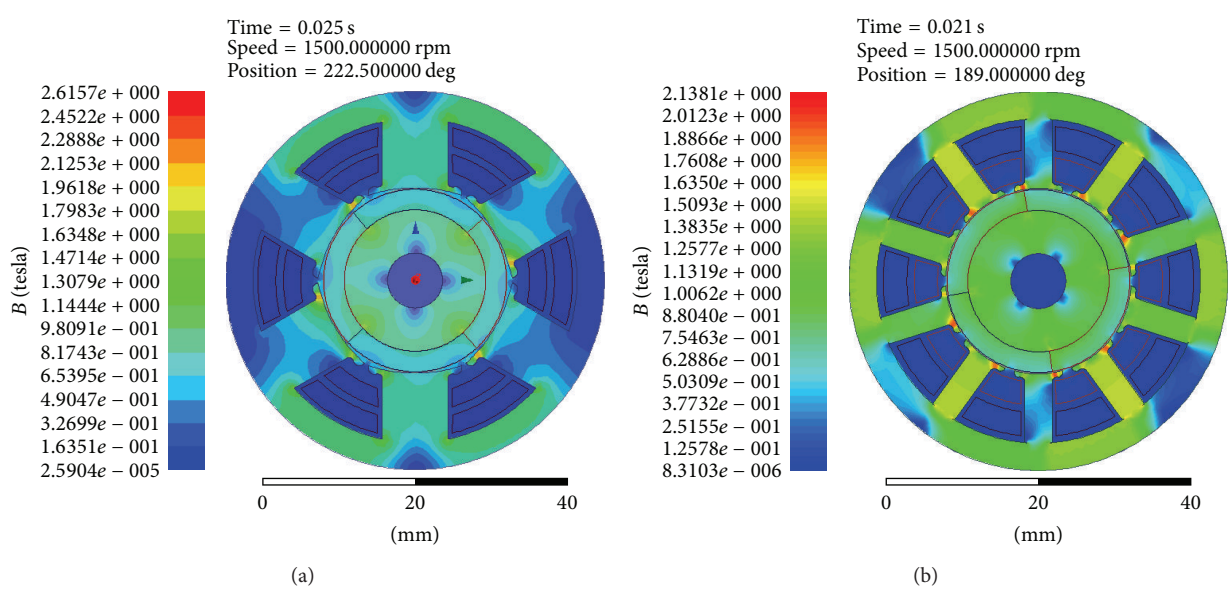


Figure 6: Magnetic flux density in three- and five-phase motors.

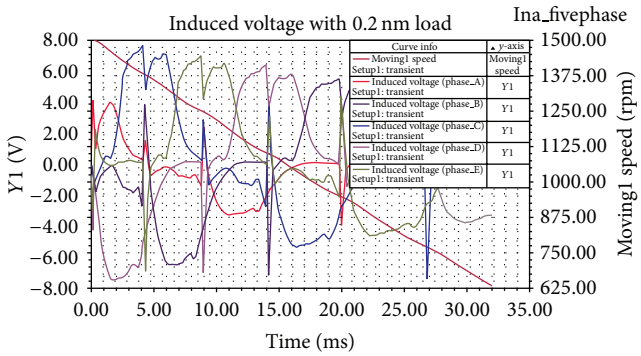


Figure 7: Five-phase induced voltage and speed (with a load torque of 0.2 Nm).

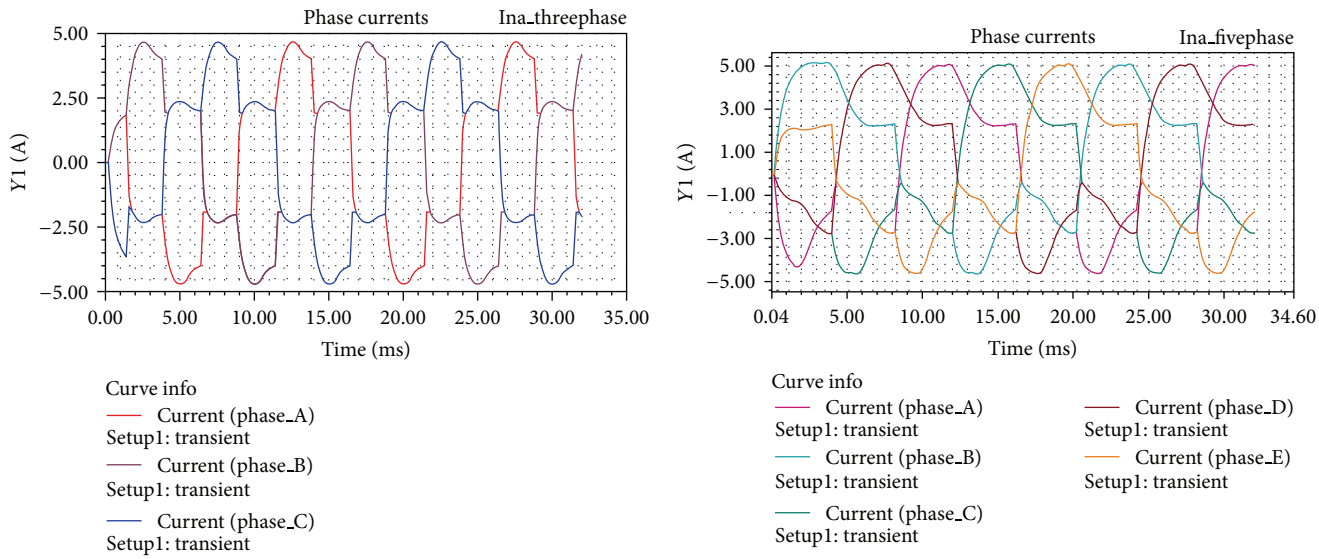


Figure 8: Three-phase and five-phase currents.

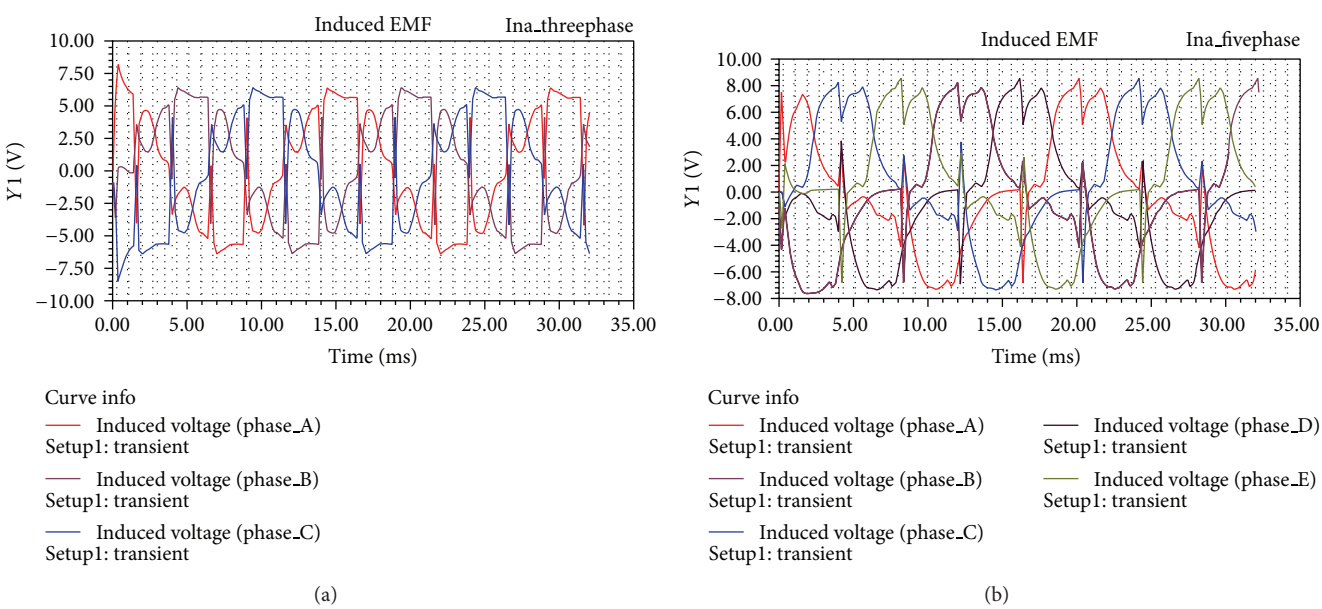
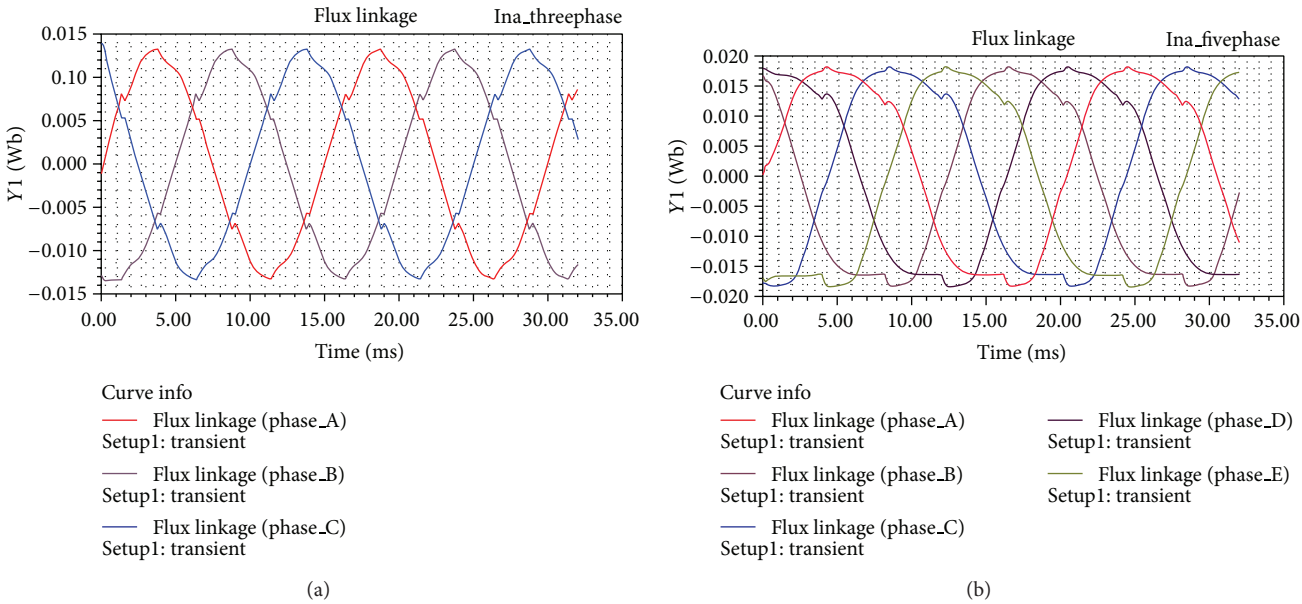
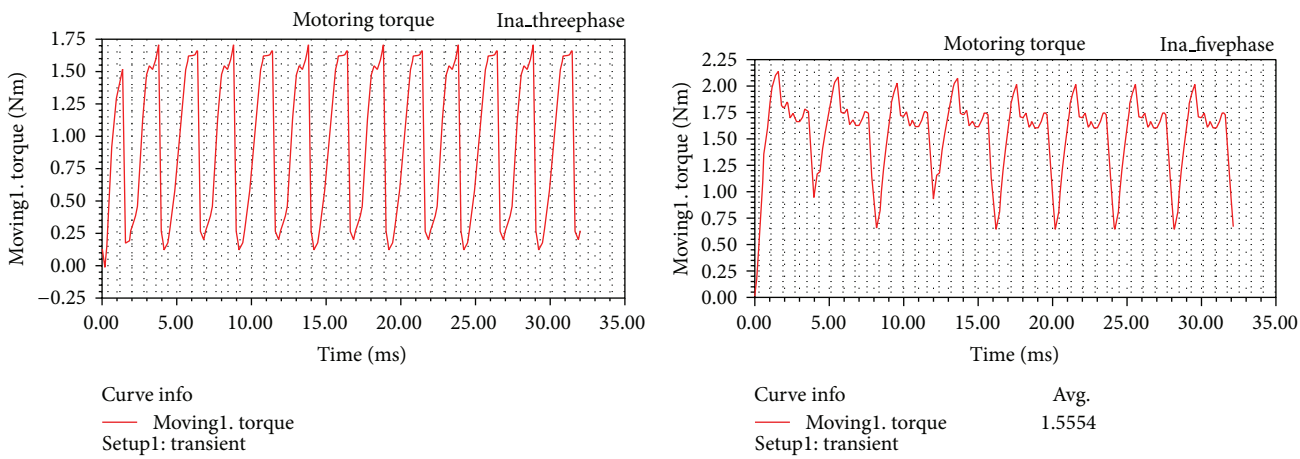


Figure 9: Three-phase and five-phase induced voltages.



(a) (b)

Figure 10: Three-phase and five-phase flux linkages.



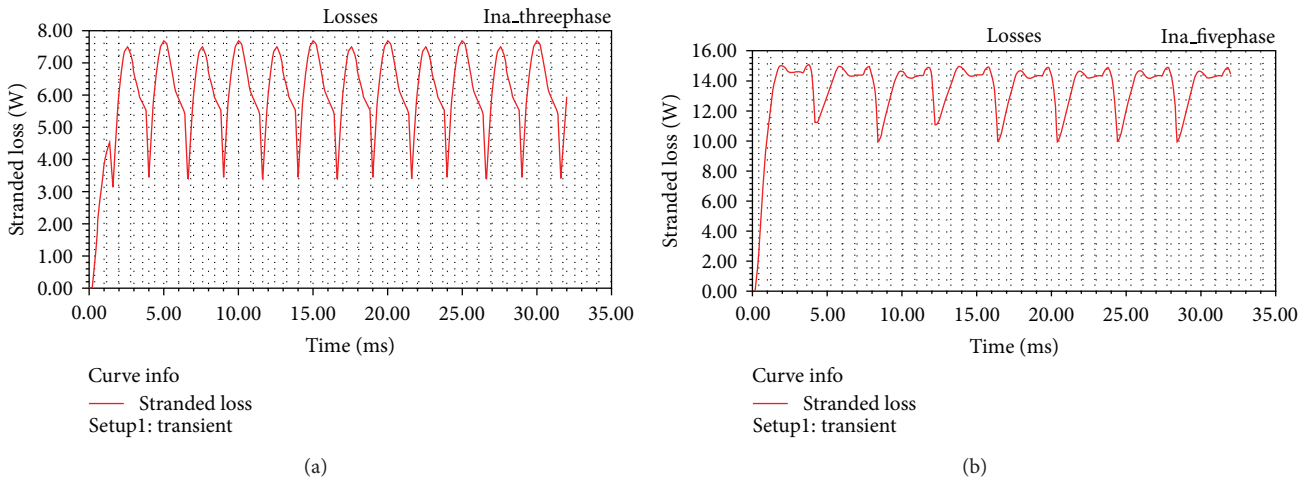
(a) (b)

Figure 11: Three-phase and five-phase motoring torques.

the torque varies from 0.92 Nm to 2.2 Nm over one cycle producing an average torque of 1.56 Nm. These results show that the torque produced in a five-phase motor running at 1500 rpm is 1.6 times the torque of a three-phase motor having the same D/L. From the above torque values, it is concluded that the torque ripple of the five-phase motor is 50.29% less than that of the three-phase motor as seen in Figure 13. Figure 12 indicates that the five-phase stranded loss is 2.19 times that of three-phase motor.

5. Conclusion

The software Maxwell 2D was adopted to establish the simulation model of five-phase brushless direct current motor by finite element analysis. The transient and dynamic performance of the motor are accurately accomplished. Simulation results show that the internal magnetic field distribution is reflected accurately and also provides a theoretical basis to make further optimal design. The main properties of the motors include electromagnetic torque, speed, winding induced voltage, and power loss, which can provide a reference to reduce torque ripple, improve the starting torque, and make further optimal design of the motor. It is also shown that the torque ripple in five-phase PMBLDC motor is low compared to its three-phase counterparts. It is concluded that the average torque produced in a five-phase motor running at 1500 rpm is 1.6 times the torque of a three-phase motor having the same D/L, and the torque ripple of the five-phase motor is 50.29% less than that of the three-phase motor. Though



(a) (b)

Figure 12: Three-phase and five-phase stranded losses.

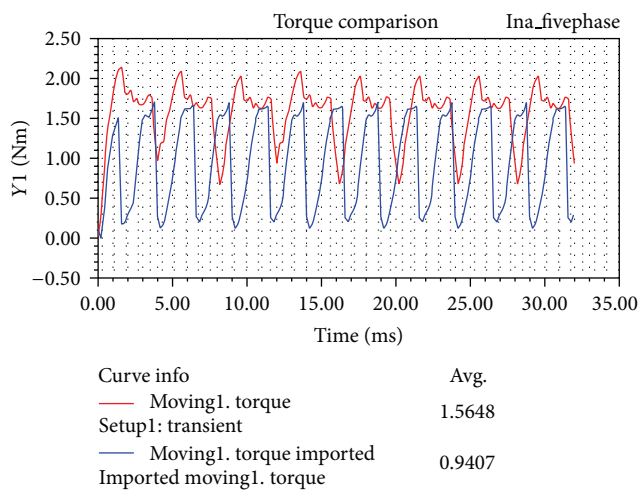


Figure 13: Three-phase and five-phase torque comparison.

the amount of torque ripple present in this analysis for three-phase and five-phase motors is not desirable, this method of analysis will enhance the theoretical understanding on motor design and its impact on motor performance.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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