INFORMATION ACCESS VIA VOICE

Except where reference is made to the work of others, the work described in this dissertation is my own or was done in collaboration with my advisory committee.

Yapin Zhong

Certificate of Approval:

Kai H. Chang
Professor
Computer Science and Software Engineering

Juan E. Gilbert, Chair
Assistant Professor
Computer Science and Software Engineering

Dean Hendrix
Associate Professor
Computer Science and Software Engineering

Stephen L. McFarland
Acting Dean
Graduate School
INFORMATION ACCESS VIA VOICE

Yapin Zhong

A Dissertation
Submitted to
The Graduate Faculty of
Auburn University
In Partial Fulfillment of the
Requirements for the
Degree of
Doctor Philosophy

Auburn, Alabama
December 19, 2003
INFORMATION ACCESS VIA VOICE

Yapin Zhong

Permission is granted to Auburn University to make copies of this dissertation at its
discretion, upon the request of individuals or institutions and at their expense. The author
reserves all publication rights.

__________________
Signature of Author

__________________
Date

Copy sent to:

Name

Date
This dissertation concentrates on the problem of designing and developing a spoken query retrieval (SQR) system to access large document databases via voice. The main challenge is to identify and address issues related to the adaptation and scalability of integrating automatic speech recognition (ASR) systems and information retrieval (IR) systems. Additionally, the mechanics of designing an effective and efficient speech user interface (SUI) pose yet another significant challenge, especially since the aim is to facilitate voice queries of large document databases. The resulting system should enable users to access large document databases effectively and efficiently. Furthermore, its language model should be capable of adapting to updates of the document databases. In this research, a framework allowing information access to large document databases via voice is presented and several approaches designed to cope with the issues of adaptability, scalability, effectiveness and efficiency are described in detail. Through
experiments performed on the TREC-9 document dataset, the performances of the new approaches were evaluated and their potential was demonstrated.
ACKNOWLEDGMENTS

The author would like to express his deep gratitude to his advisor, Dr. Juan E. Gilbert, for his patient guidance, valuable advice, and continued encouragement throughout his studies. Sincere thanks are also due to his two graduate committee members, Dr. Kai H. Chang and Dr. Dean Hendrix, for their reviewing and advising efforts. In addition, the author would like to thank Celeste German for her reviewing and valuable comments. Finally, deepest thanks to author’s wife, Weihong Hu, for her help while conducting the experiment and constant support.
Information Access via Voice

Yapin Zhong

Dept. of Computer Science & Software Engineering
Auburn University
Outline

- Motivation
- Background
- Research Challenges
- A Framework of Spoken Query Retrieval
- Experiments and Research Findings
- Conclusions
Motivation

- A very large part of the world population does not have access to either computers or the Internet
- Very tiny visual interfaces make users feel quite uncomfortable
- Blind or partially-sighted users are not able to access information visually
Background

Two categories: spoken document retrieval (SDR) and spoken query retrieval (SQR)

In SDR, written queries are used to search speech archives for relevant speech information

SQR uses spoken queries to retrieve relevant textual information
Voice Server

Databases

Nuance Voice Platform

VoiceXML Interpreter & Controller

Speech Recognition
Audio Recording
DTMF

Speech Synthesis
Audio Playback

Telecommunications Infrastructure
Automatic Speech Recognition

$$\arg \max_W P(W \mid X) = \arg \max_W P(X \mid W) \cdot P(W)$$

**User Speech**

- Parameterization
- Pattern Matching
- Transcriptions

**Acoustic Models**

**Language Models**
Three major properties in SQR

- Spoken queries are usually very short
- Spoken queries usually need a very large vocabulary
- Query processing is required to be in close to real time
Research Challenges

- A lack of adaptability and scalability in integrating language models between ASR and document Information Retrieval systems.
- Difficult to meet the critical aspect of “real time” user expectations.
- A general lack of effectiveness and efficiency in designing speech user interfaces.
The Language Size Vs. The time Consumed
The Language Size Vs. the Word Recognition Error (WRE) Rate

![Graph showing the relationship between vocabulary size and WRE rate. The x-axis represents vocabulary size (100 to 3000), and the y-axis represents WRE rate (0% to 100%). The graph shows an increasing trend in WRE rate as vocabulary size increases.]
Query Coverage Compared to the Language Size

<table>
<thead>
<tr>
<th>Vocabulary Size (k)</th>
<th>25</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Query Coverage [FM02] (percent)</td>
<td>62.2</td>
<td>79.2</td>
<td>83.9</td>
<td>85.9</td>
<td>87.1</td>
<td>87.9</td>
</tr>
</tbody>
</table>
Problems in SQR Interfaces

- Speech is transient but graphics are persistent
- Speech is invisible
- Speech is asymmetric
A Framework of SQR

- Design Principle
- System Architecture
- Context-Aware Language Model
- Bisecting K-Medioids Method
- Voice Navigator
- Information Verbalization
Design Principle

- Integrating ASR systems with existing IR systems, but not “simply combined by the way of input/output protocol” [FII02]
- Language models that will enable both adaptability and scalability so as to satisfy the document retrieval requirements for large databases
- Effective and efficient SQR user interfaces
System Architecture
Context-Aware Language Model (CALM)
Procedure to construct CALM

1. Preprocess and Index the collected documents
2. Represent each document with a vector
3. Cluster the collected documents into certain groups
4. Represent the center of each group with an important document
5. Construct the CALM with a set of important keywords from the centered document
Document Clustering Analysis

- Assign a set of documents to the different groups based on their similarity
- Closely associated documents tend to be relevant to the same requests
- Document clustering should result in more effective, as well as more efficient, retrieval
- Hierarchical and partitioning clustering
Bisecting K-Medioids (BKMdd)

- A medioid representative
- An objective function to control the iterative optimization:

\[ J = \sum_{i=1}^{2} \sum_{j=1}^{n} d_{ij}^2 \]

- A two-phase clustering method
The bisecting phase:

Set iter = 0;
Repeat
    Compute by using (2.2.1);
    Assign \( V^{old} = V \);
    Compute the new medioid set by using
    \[ J = \sum_{i=1}^{2} \sum_{j=1}^{n} d_{ij}^2; \]
Until (iter = MAX_ITER)

The K-Medioids phase:

Set K;
Repeat
    Pick a cluster to split by using
    \[ \partial(M) = \frac{1}{M} \sum_{j=1}^{M} d_{ij}^2; \]
    Find two sub-clusters by using Bisecting phase;
Until K

BKMdd
# Voice Navigator (VN)

<table>
<thead>
<tr>
<th>Category</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>Help</td>
</tr>
<tr>
<td></td>
<td>Main menu</td>
</tr>
<tr>
<td></td>
<td>Try again</td>
</tr>
<tr>
<td></td>
<td>Exit (Goodbye)</td>
</tr>
<tr>
<td>Query</td>
<td>By source</td>
</tr>
<tr>
<td></td>
<td>By field</td>
</tr>
<tr>
<td>Results</td>
<td>Literal Response</td>
</tr>
<tr>
<td></td>
<td>Cooperative Response</td>
</tr>
<tr>
<td>Browsing</td>
<td>Read by title</td>
</tr>
<tr>
<td></td>
<td>Read by abstract</td>
</tr>
<tr>
<td></td>
<td>Previous</td>
</tr>
<tr>
<td></td>
<td>Next</td>
</tr>
<tr>
<td></td>
<td>Repeat</td>
</tr>
<tr>
<td></td>
<td>Stop</td>
</tr>
<tr>
<td></td>
<td>Save</td>
</tr>
</tbody>
</table>
VN Dialogues

- Main Menu Dialogue
- Query Dialogue
- Results Dialogue
- Save Dialogue
Diagram of the VN

Welcome Message

Main Menu Dialogue

Query Dialogue

Results Dialogue

Save Dialogue

Confirm Email

Confirm MyLibrary
Information Verbalization

The use of computer supported, auditory interactions to amplify understanding of abstract and/or large data

- Literal Response (LR)
- Cooperative Response (CR)
- Mixed Intelligent Response (MIR)
- Cluster-based Intelligent Response (CIR)
MIR Strategy

Combine LR and CR strategies to present all documents in the ranked results set one by one if there is no response from the user. If the system receives any responses from the user, MIR will stop the current presentation immediately, then process the action quickly.
CIR Strategy

- The results are clustered before present action
- The results are ranked within each cluster
- The top ranked documents are selected from each cluster
- The number of the documents to be presented is usually five but never beyond nine
Experiments and Research Findings

- Experimental protocol
- Data collection methods
- Participants and procedure
- Evaluation Metrics
Experimental Protocol

Materials

Large document databases:

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of documents</td>
<td>348,566</td>
</tr>
<tr>
<td>Size of collection in Mb</td>
<td>381.5</td>
</tr>
<tr>
<td>Average document length</td>
<td>195</td>
</tr>
<tr>
<td>Average document length (unique terms)</td>
<td>111</td>
</tr>
</tbody>
</table>
Data Collection Methods

- Dialogue recordings
- System logs
- User surveys
Participants and Procedure

- 39 college level students
- Read the instructions
- Access the system
- Search documents
- Fill out the survey
Evaluation Metrics

- Spoken query metrics
- Task success metrics
- Interface efficiency and quality metrics
- User satisfaction
Spoken Query Metrics

- Female/Male: 48.53
- Native/Second: 51.47
- Under/Grad: 79.41
## Numbers of Users, Queries, and Terms

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Number of Participants</td>
<td>39</td>
</tr>
<tr>
<td>Total Number of Spoken Queries</td>
<td>203</td>
</tr>
<tr>
<td>Average Number of Spoken Queries per User</td>
<td>5.21</td>
</tr>
<tr>
<td>Number of Unique Queries</td>
<td>138</td>
</tr>
<tr>
<td>Total Number of Spoken Terms</td>
<td>542</td>
</tr>
<tr>
<td>Total Number of Uniquely Spoken Terms</td>
<td>99</td>
</tr>
<tr>
<td>Mean Number of Terms</td>
<td>2.66</td>
</tr>
</tbody>
</table>
Users by Number of Queries

- SQR: 70% of users more than a single query
- Excite: 67% of users had one and only query
- Spoken query modification was a strong trend
Significant association between the spoken queries and the document reviewed.
Queries by Number of Terms

- SQR: More than 60% of the queries less than or equal to 2 terms. The mean of terms was 2.66
- Excite: The mean of Web search terms was 2.21
Term Frequency Distribution

24 terms covers 82.8% of all queries
The CALM Coverage

- The CALM consisted of 389 terms which represent at least a 93% coverage of all the most important terms found in all documents.
- There were 138 unique spoken queries covering 99 unique terms.
- There were 8 unique terms that were spoken by participants that did not appear in the CALM.
- The experimental coverage of the CALM was 93.10%.
Task Success Metrics

- The mean of Documents Found was 1.54
- Significant as a function of users’ experience
- No significant difference between the MIR & CIR strategy
- Significantly negatively correlated to Barge Ins, Query Terms Mis-recognition, and Word Recognition Error (WRE)
Interface Efficiency Metrics

- System Turns and User Turns were positively associated with Query Term Mis-recognitions and Barge Ins
- Elapsed Time was positively associated with Query Term Mis-recognitions, Barge Ins, and Spoken Queries
Interface Qualitative Data

ASR rejections were positively associated with WRE, Barge Ins, and Spoken queries.
The WRE rate for the entire set of spoken query utterances was 6.87%.
The average user satisfaction rating was 82% based on 31 satisfactory factors.
Task Success & Results Presentation Strategies

- Task Success was significantly positively related to Results Presentation Strategy
- No significant difference in the Task Success measure as a function of the Results Presentation Strategy
Users’ Satisfaction Perceptions with Touchtone Experience

No significant difference between subjects who had touchtone and no touchtone experience
Users’ Satisfaction Ratings with SUI experience

No significant difference as a function of subject SUI experience
Conclusion

- Achieved a high user satisfaction rating
- Achieved a high Task Success rating
- Performed well with regard to interface efficiency
- Kept its promise of an improved interface quality
- The CALM was developed with a high coverage
Contributions

- Identified and addressed the issues and constraints that the effects of a language model on the ASR performance
- Addressed the issues related to SUI that arise in performing SQR tasks
- Studied and investigated document clustering techniques and VoiceXML technologies
Contributions (Cont’d)

- Proposed an architecture of SQR systems for large document databases
- Defined a Context-Aware Language Model (CALM). A document clustering technique was employed to build such a CALM
- Defined an effective and efficient dialogue framework to facilitate SQR tasks
- Proposed two information verbalization strategies to present the retrieval results.
Future Research

- Study how to combine a visual and verbal user interface to interact with the user to enhance the user’s information access.
- Document summarization may improve the user’s information access.
- Temporal and contextual factors may affect the user’s information needs.
Thanks

- Questions ?
- Comments ?
References
