Voice and Multimodal Technology for the Mobile Worker

Kondratova, Irina

Publisher's version / Version de l'éditeur:

Itcon, Special Issue Mobile Computing in Construction, 9, 2004

National Research Council Canada
Institute for Information Technology

Conseil national de recherches Canada
Institut de technologie de l'information

NRC · CNRC

Voice and Multimodal Technology for the Mobile Worker *

Kondratova, I.
August 2004

* published in ITcon, Volume 9, Special Issue on Mobile Computing in Construction. August 2004. pp. 345-353. NRC 47423.

Canada

VOICE AND MULTIMODAL TECHNOLOGY FOR THE MOBILE WORKER

SUBMITTED: October 2003
REVISED: April 2004
PUBLISHED: August 2004 at http://www.itcon.org/2004/24/
EDITOR: D. Rebolj and K. Menzel

Irina Kondratova, Group Leader, Human Web Group
National Research Council of Canada, Institute for Information Technology e-Business, Canada
email: irina.kondratova@nrc-cnrc.gc.ca

***SUMMARY**: The availability of real time, complete information exchange with the project information repository is critical for decision-making in construction, as information frequently has to be transmitted to and received from the project repository right on site. Information and Communication Technology, specifically wireless communications through mobile device, is seen as a key enabler of leading edge, innovative and powerful field solutions. However, the widespread usage of mobile devices is limited by antiquated and cumbersome interfaces. Speech recognition, along with VoiceXML technology on handheld smart device, should play a major role in overcoming user interface limitations for mobile devices and improve their usability for industrial field applications. This paper discusses the advantages of using VoiceXML technology for voice-enabled, construction field applications. It presents a pilot application of voice technology for inventory management, and outlines the direction of future research in the area of voice and multimodal communications that enable information mobility in AEC industry.*

***KEYWORDS:** mobile worker, multimodal interactions, speech recognition, VoiceXML, voice user interfaces*

1. INTRODUCTION

We are rapidly moving away from the Desktop and Laptop Web paradigms towards the Mobile Web paradigm, where mobile, smart devices such as the Smart phone, Pocket PC, PDA (Personal Digital Assistant), hybrid devices (such as phone-enabled PDAs or Pocket PCs), and wearable computers will become powerful enough to replace laptop computers in the field and will be widely used for real time communication, of construction project information, to project repositories or between project participants. The availability of real time, complete information exchange with the project information repository is critical for decision-making in the field of construction site inspection, as information frequently has to be transmitted to and received from the project repository right on site without the engineer making a costly additional field trip (Rankin 2002, Meissner 2002).

The potential of using mobile, handheld devices in the field for real time communication is limited by antiquated and cumbersome interfaces. A small screen size and the need to use a pen to enter data and commands present a great inconvenience for field users - especially if their hands are busy using other equipment, or instruments. Speech processing is one of the key technologies to simplifying the use of handheld devices for mobile workers (Burkhardt et. al 2002, IDC Viewpoint 2002). Software applications developed using speech processing technologies allow “hands free” information input and retrieval and thus can help to overcome the limitations of the user interface of a field, handheld computing device (Srinivasan and Brown, 2002). However, this technology is limited to only one form of input and output – the human voice. The use of multimodal communication will help to overcome this constraint. Multimodal communication technology can be described as the integration of visual and voice interfaces, through the delivery of combined graphics and speech, on handheld devices (Hjelm, 2000). This technology enables comprehensive information communication for the mobile worker and supports timely and informed decision-making in the field.

The migration of speech recognition to smaller devices, such as Pocket PCs, Smart phones, etc. is enabled by the introduction of efficient speech recognition engines that can better handle noise and variations in speech, as well as, by the development of greater computing power for small devices, and faster, bigger and cheaper processors to support the speech engines. The Kelsey Group projects that software licenses from embedded speech applications will grow from $ 8 million US in 2002 to $227 million in 2006. This would make the embedded speech recognition industry one of the fastest-growing segments of the speech market (Kumagai, 2002). In addition, the introduction of wearable computers, in the field, will expedite the widespread adoption of speech recognition technology for the mobile worker. A feasibility study, that focussed on the use of wearable computers in construction (Fuller and Sattineni, 2002), showed that it is largely the relatively high cost of rugged, industrial, wearable computers that prevents the wide spread use of them on construction sites.

The Internet is increasingly becoming accessible through low cost, ubiquitous “Internet appliances” such as the telephone. Voice technology, and, especially VoiceXML, is the enabling technology that allows people to interact with computers over the telephone using natural speech dialogues. VoiceXML technology allows people to access the Web from anywhere they can make a call, thus providing increased access to goods and services, as well as to customers (Abbott 2002).

This paper discusses the advantages of using VoiceXML technology for speech-enabled, mobile industrial applications. It also presents a pilot application of this technology for inventory management, and outlines the direction of future research in the area of construction information mobility and multimodal interfaces.

2. MOBILE TECHNOLOGIES FOR THE CONSTRUCTION INDUSTRY

2.1 The construction industry in Canada

The Architectural, Engineering and Construction (AEC) industry in Canada is dominated by small and medium size enterprises and is geographically dispersed. It represents a large industrial sector of Canada (12% of GDP). However, it has a very high degree of fragmentation and no prominent players to enforce Information and Communication Technology (ICT) solutions on projects (Industry Canada 1998, Rivard 2000). In addition, the industry is project oriented, which means that ICT must be deployable within one project to all partners. Most projects are “virtual” organizations set up for the duration of the contract with temporary and short-term business relations.

Many challenges in today’s construction arise from poor access to the right information, at the right time, for efficient decision-making and from a general communication breakdown between the project participants. In this environment, ICT and, especially wireless communications, are seen as the key enablers and instruments of leading edge, innovative and powerful solutions of the future (Filos, 2002). It is estimated that, through improved communication processes, ICT can bring potential time and cost savings of 10% to 20% (Rankin, 2002).

2.2 Mobility of information to support decision-making

Research and development efforts in computer-integrated construction, that are focused on solving issues related to construction information fragmentation and communication breakdown, have already established the foundation for an integrated project repository. This Web based repository allows all construction project participants to exchange information in an open, industry standard environment (Russel and Froese 1997, O’Reilly et. al 2003). However, access to project information on a construction site is often limited by the on-site network and Internet infrastructure that is frequently not available, and thus the benefit of timely and informed decision-making is not a current reality.

There are some experimental research projects on the use of mobile devices for field data collection (Mrawira et al, 2002). However within these projects, the communication with the project information repository is conducted asynchronously by downloading field data from mobile devices onto desktop computers and then transferring this information into the repository. To take full advantage of the recent developments in wireless communications and mobile computing, it is important to establish a framework for augmenting the existing, integrated, project repository environment with mobile wireless devices. The mobile worker, situated at the construction site, will be able to use these smart devices to communicate with the project information repository in real time, thus enabling more timely and informed decision-making on the project.

2.3 Current studies on mobile field applications

Recently, several research projects have been initiated to investigate the use of mobile devices for synchronous project information communication. The SABARECO project, funded by the EU IST 5th Framework, demonstrated the advantage of satellite-based communication between remote construction sites using standards such as TCP/IP and IFC/XML (Boehling, 2002). Some researchers explore the use of a handheld computer for

3D visualization of design components and assemblies of construction projects (Shiratuddin et al, 2002). Others work in the area of mobile product models that structure the project information so that it could be effectively displayed on mobile devices (Rebolj et al, 2002). Research work is also being carried out to investigate context sensitive data management on mobile devices, adapting the amount of information delivered to the device based on the computing power and the size of the screen (Menzel et al, 2002).

In several field, mobile computing projects, due to the importance of location in fieldwork applications, handheld computers were augmented with a GPS receiver to reference the location. For example, a handheld computer with a GPS receiver was used for construction damage assessment after the September 11 terrorist attack (Bacheldor, 2002). Moreover, for location-based remote monitoring applications, other sensors, such as temperature and moisture sensors, or accelerometers could be connected to a handheld device. Some examples of the location-referenced, field applications include field data collection, control of environmental sampling during site inspection, and on-site training (Giroux et al, 2002).

However, recently it has been recognized that the potential of the widespread usage of mobile devices is limited by usability shortcomings. More research is waiting to be conducted on technologies that improve the usability of handheld computing devices in the field (Hjelm, 2000). The small screen size and the need to use a pen to enter data and commands present a great inconvenience for field users - especially if their hands are busy using other equipment, or instruments. The investigation of current technologies that could help overcome these limitations is one of the goals of the ongoing "Voice and Multimodal Field Access" research program at the National Research Council of Canada Institute for Information Technology e-Business. We believe that speech recognition, along with VoiceXML technology on handheld smart devices will play a major role in overcoming user interface limitations for mobile devices and improve their usability for industrial field applications.

3. VOICE TECHNOLOGY FOR THE MOBILE WORKFORCE

3.1 Voice-enabled Web paradigm

In spite of the recent progress in the introduction of information technology in to the AEC and Facility Management industries, the telephone is still the most widely used and the most effective information communication tool (Flood et al 2002, Egbu and Botterill 2002). Thus, a technology that can utilize the convenience of a mobile telephone, and provide real time access to the wealth of information stored in the construction project information repository or a corporate database, deserves special attention.

The technology under investigation is VoiceXML technology for voice-enabled information access. VoiceXML stands for Voice Extensible Markup Language. Currently, VoiceXML is the major W3C standards effort for voice-based Web services (W3C, 2004). VoiceXML technology follows the same model as the HTML and Web browser technologies. Similar to HTML, a VoiceXML application does not contain any platform specific knowledge for processing the content. The platform specific processing capability is provided through the Voice Gateway that incorporates Automatic Speech Recognition (ASR) and Text-to-Speech (TTS) engines, along with a Voice Browser. The Voice Gateway architecture is presented in Fig.1. It uses the familiar client – server paradigm. The software application developed using VoiceXML accepts user input in the form of speech and DTMF (touch tones produced by a phone) and generates output in the form of synthesized speech and pre-recorded audio. Thus it allows "hands free" information entry and retrieval, which helps to overcome some limitations of the user interface of a field handheld computer (Moraes, 2002).

The advantage of using VoiceXML technology, to build voice-enabled services, is that companies can build interactive voice response (IVR) systems using the same technology they use to create visual Web sites - significantly reducing the cost of construction of corporate voice portals. A voice portal provides telephone users, including mobile phone users, with a voice interface to access and retrieve Web content. The potential of voice portals is as big as the reach of the telephone. According to Kelsey Group's projections, 18 million consumers will use some kind of speech-driven service to access the Web by 2005 and revenue from this market could top $12 billion (Caris, 2002).

VoiceXML allows providers to deliver Web services using voice user interfaces (VUIs). Developers can use VoiceXML to create audio dialogues that feature synthesized speech, digitised audio, recognition of spoken and touchtone key input (DMTF), recording of spoken input, telephony, and mixed-initiative conversations (Srinivasan and Brown, 2002). VoiceXML allows the development of speaker independent IVR systems. The words or phrases that a VoiceXML application must recognize are usually included in a grammar. Large grammars can cause application problems because they can result in recognition errors. Small grammars can cause VUI problems because they require prescriptive prompts that limit the use of natural language dialog (Beasley et al, 2001). Small grammars, however, could be used successfully for most industrial users that are trained in using the voice application.

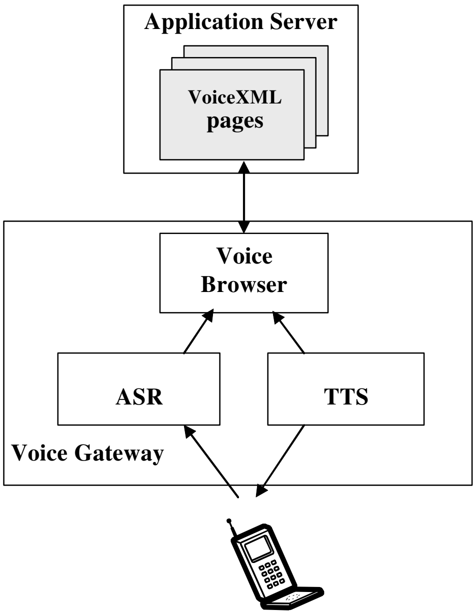

FIG.1. Voice gateway architecture

3.2 Voice applications for field users

There are quite a few existing speech recognition applications that use VoiceXML technology to provide voice-enabled services to customers. Most frequently VoiceXML has been used for building information services. These services, usually offered by wireless service providers, allow customers to access news, email, weather, tourist and entertainment information, and business directories. They also include customer service applications where customers can, using natural speech, access their account balances, register their travel reservations, check travel information or find vehicle information and register their vehicles. However, there are only a handful of existing applications that utilize the potential of voice-based information retrieval for industrial purposes.

For example, Florida USA Power and Light Co. is using a VoiceXML based system for field restoration crews. Using mobile phones restoration crews can find out about storm-damaged equipment and report back to the system on the status of the job. A crewmember uses voice commands to interact with the application, identifying the work ticket and the status of the job. The data is then automatically entered into the outage management system, while audio commands and online help are provided to assist the crewmember throughout the transaction. After completion of the initial transaction, the crewmember can request the status of the next job to be assessed, thus eliminating possible duplication of work assignments and unnecessary travel time.

Considering the widespread use of mobile phones, by mobile workers and field crews, there is also opportunity to apply VoiceXML technology for other industrial applications, including applications in construction, manufacturing, power and resource industries. These industries can also benefit from voice-enabling their operations. The ongoing NRC research program on voice and multimodal technologies specifically targets industrial applications of speech recognition technology. In the framework of this program, a prototype inventory management application was developed using VoiceXML technology.

4. VOICE INVENTORY MANAGEMENT SYSTEM

4.1 System design

The Voice Inventory Management System (VIMS) prototype, developed by the NRC IIT e-Business Human Web group, allows a mobile worker to easily retrieve product and warehouse information out of the back-end warehouse, product database in real time, using a mobile or regular phone and natural speech dialog. The control flow diagram for the VIMS system is presented in Fig. 2.

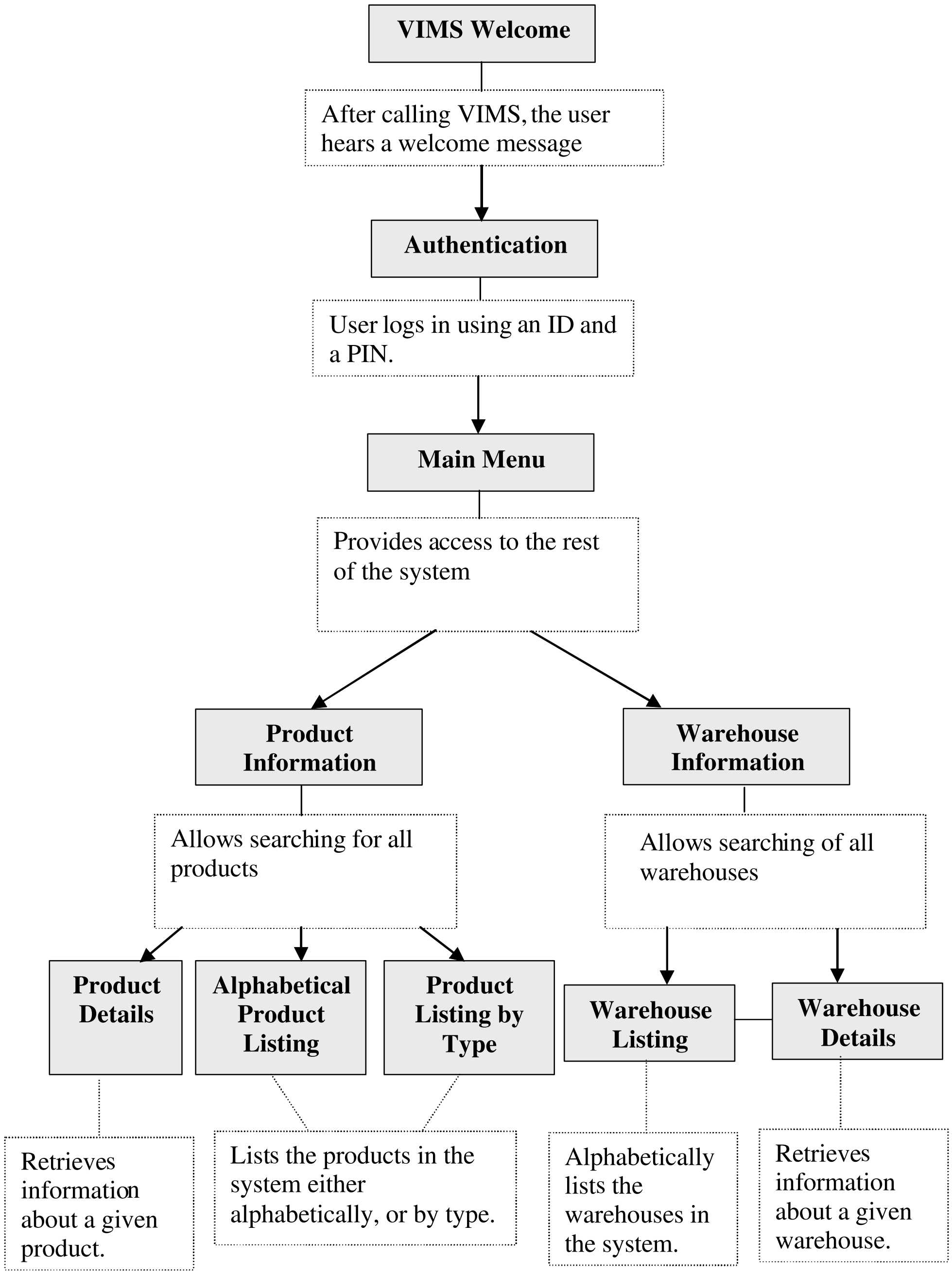

FIG.2. Voice Inventory Management System control flow diagram

The system has an authentication menu to only allow authorized access to the system. To enter the system, users must say their name and a personal identification number. This number could be spoken or entered using a touchtone keypad. The VIMS application keeps track of a series of products and warehouses in a database. Each product and warehouse has a number of attributes. Each product has a price, product number and description and is associated with the warehouses the product is located in. Each warehouse has an address, and a listing of the contents of that warehouse. The system also keeps track of product types - represented by a tree that links particular types of products together. The user has the option of browsing through a hierarchical menu of product types, which is useful if the name of a product is not known.

The user of the system can also ask directly about a particular product or warehouse and request information regarding that product or warehouse. A natural speech dialog is used. For example, a user looking for information on aluminium window frames might ask, "What is the price of an aluminium window frame?" or "What warehouses are the aluminium window frames located in?"

In addition, an extensive listing system, incorporated into the program, allows the user to browse an alphabetical listing of all products and warehouses stored in the system. As searching through an alphabetical list of dozens of items can be time consuming, the user also has the ability to skip to items beginning with a certain letter. All products in the back-end, warehouse database are entered into the VIMS speech recognition grammar, so that the grammar is updated dynamically concurrently with the information on current products and warehouses in the database.

4.2 Voice User Interface Design

In spite of the current improvements in speech recognition technology, it is still considered to be best suited for producing niche market solutions for people that have their hands busy in some activity or people that cannot use their hands (Weinschenk and Barker, 2000). Speech technology has its own unique set of human factor issues. These issues, among others, include managing high human expectations of computers and speech by maintaining a realistic outlook on what a computer can understand and respond to and teaching users to use constrained speech to get correct results. It is also important to try to minimize the memory load, while using the speech-only interface, by limiting the number of menu choices that the user has to memorize, as well as, provide feedback to the user during processing delays in speech applications (Lai, 2002).

To uncover problems with the design of speech applications, it is important to conduct usability studies in the environments in which real users will use the application. To design an effective usability study it is customary to conduct a preliminary pilot usability study that helps to refine the testing procedures and the design of user questionnaires.

4.3 System Evaluation

A pilot usability study for a VIMS system, that provides voice access to a database containing entertainment products such as videos and books, was carried out on a group of twelve Web proficient, university student users. This pilot study showed that, with minimal training, users could easily navigate through the voice user interface, draw a sketch of the VIMS navigational structure and retrieve required information on the products and on warehouses where these products are located. A further, wider scale usability testing program needs to be conducted in the future with a group of industrial field users to evaluate the feasibility of using VoiceXML technology in the field.

The results of in-house speech recognition accuracy testing for the VIMS prototype showed that a native English speaker using a VIMS prototype system, even in a noisy industrial environment, retrieves required product information 95 times out of 100. Subsequent testing, conducted using the computer product database containing more than 1000 items, indicated no decrease in the accuracy of speech recognition for a large database. However, the processing time increased with increases in the size of the database, due to increases in the size of the grammar (Kondratova, 2003). It is possible to create sub-grammars in the VoiceXML application that shorten grammar-matching time, but make the navigation through the voice user interface more complex.

The VIMS application is designed to be used in a variety of locations with different mobile telephony equipment such as cellular phones or phone-enabled handheld devices. Testing on mobile devices such as the RIM Blackberry Wireless and the Handspring Treo has been done for the VIMS prototype, using an in-house Voice Genie VoiceXML platform. These tests were performed primarily to investigate how noise affects the operations of the application on different devices. All devices performed well in the artificial "industrial noise" conditions in laboratory testing. Further testing of the prototype, with different mobile devices, needs to be done in the field. The grammar and the voice user interface design are both important components of VoiceXML application usability and will require additional research and testing.

5. MULTIMODAL AND LOCATION BASED FIELD SERVICES

The advantages afforded by the field use of the VoiceXML technology in providing field access to corporate and project information could be substantial. However, VoiceXML technology, for now, is limited to only one form of input and output – the human voice. To facilitate speedy field data collection and timely decision-making, especially in the case of construction field inspection, where information is largely based on visual observations, it would be beneficial to use multimodal mobile devices capable of delivering voice, text, graphics and video. For example, "hands free" voice input can be used by an engineer conducting construction site inspection to request information from the integrated project repository, using a hybrid phone-enabled Pocket PC and a wireless, Bluetooth headset piece. Then the requested information can be delivered as text, an image, CAD drawing, or video, if needed, directly to the Pocket PC screen.

By combining a multimodal, mobile, handheld device with a GPS receiver and a Pocket GIS system, the gathered inspection information could be automatically linked to its exact geographical location. The linkage of information to a specific location could serve multiple purposes: i.e. getting the precise location of the data collected, helping timely retrieval of information related to the specific location, and providing an option of "pushing" location relevant information to the field crew. Currently, commercially available Pocket PC GPS technology allows for location accuracy of several meters. By utilizing differential GPS technology higher location accuracy (decimetres range) becomes possible.

Because of the foreseen benefits of using speech-enabled mobile devices to communicate data collected during construction site inspection into the integrated project information repository, the focus of future research on voice and multimodal technologies for information mobility in AEC industry will be on the investigation of:

- processes and procedures, used during the construction inspection process that could be improved using speech recognition technology;
- the feasibility of VoiceXML technology and multimodal communications, on handheld devices, to communicate the location-referenced inspection information from the construction site into the integrated project information repository;
- the existing and developing data communication standards, protocols and tools that will support wireless communication of location-referenced, project information within the integrated construction project repository environment.

6. CONCLUSIONS

Rapidly increasing computing power for mobile devices allows their utilization as efficient field communication tools for construction project information. However, the limitations of a small screen size and a small (or absent) keyboard present usability challenges for field users. Speech recognition, along with VoiceXML technology and multimodal communications, should play a major role in overcoming the user interface limitations of mobile devices. Research and development efforts conducted by the author up to date confirmed the feasibility of using voice technologies, with mobile devices, for real time information access and entry. Further performance and usability studies, as well as extensive system evaluations should be conducted with industrial users in the field. The future research will investigate the applicability of this technology, as well as multimodal communications on mobile devices for construction site inspection, quality control data entry, or for other field applications in the AEC industry.

The research program, on voice and multimodal field access to information, focuses on the development of mobile applications that allow real time communication of site information, including site inspection results, quality control results, etc. into the integrated construction project repository. This communication should be conducted using different modalities that are appropriate for the mobile devices used, the user's abilities and the environmental context. The outcome of this research program will bring solutions that provide better access to the right information at the right time for numerous AEC project participants.

7. ACKNOWLEDGEMENTS

The author would like to acknowledge the support provided for the project by the National Research Council Canada.

8. REFERENCES

Abbott K. R. (2002). *Voice enabling Web applications: VoiceXML and beyond.* APress, Springer-Verlag, New York.

Bacheldor B. (2002). Handheld system assesses damage to see how buildings survived, *Information Week*, March 18, 2002.

Boehling H. (2002). Satellite-based remote multi-project reporting and controlling in construction industry applying IFCs and XML standardization, *Proceedings of the Conference on eWork and eBusiness in Architecture, Engineering and Construction*, Turk and Scherer (eds), Swets & Zietilinger, Lisse, 635-636.

Burkhardt J., Henn. H., Hepper S., Rindtorff K. and Schack T. (2002). *Pervasive Computing. Technology and architecture of mobile Internet applications*, Addison-Wesley, New York.

Caris F. (2002) The Evolving Voice-Web experience, *Wireless Week*, September 16, 2002, http://wirelessweek.com/ [Last accessed April 2004].

Egbu C.O. and Boterill K. (2002). In formation technologies for knowledge management: their usage and effectiveness, ITcon, Vol.7, 125-136, http://www.itcon.org/ [Last accessed April 2004].

Filos E. (2002). European collaborative R&D projects related to the "Smart organization". A first evaluation of activities and implications for construction, *In the Proceedings of the Conference on eWork and eBusiness in AEC*, Turk and Scherer (eds), Swets and Zietilinger, Lisse, 27-32.

Flood I., Issa R.R.A. and Caglasin G. (2002). Assessment of e-business implementation in the construction industry, *In the Proceedings of the Conference on eWork and eBusiness in AEC*, Turk and Scherer (eds), Swets & Zietilinger, Lisse, 27-32.

Fuller. S. and Sattineni A. (2002). Investigating the use of wearable computers in construction, *Proceedings of the First International Conference on Construction in the 21st Century, Challenges and Opportunities in Management and Technology*, Miami, Florida, 583-588.

Giroux S., Moulin C., Sanna R. and Pintus A. (2002). Mobile Lessons: Lessons based on geo-referenced information, *Proceedings of E-Learn 2002*, 331-338.

Hjelm J. (2000). Research applications in the mobile environment, in *Wireless Information Services*, John Wiley and Sons, New York.

IDC Viewpoint. (2002). Five segments will lead software out of the complexity crisis, by A.C. Picardi, December 2002, Doc #VWP000148.

Industry Canada. (1998). Sector competitiveness framework series; Construction overview and prospects.

Kondratova I.L. (2003). Voice and multimodal access to AEC project information, Mobile Computing in Architectural, Engineering and Construction, *10th ISPE International Conference on Concurrent Engineering: The Vision for Future Generation in Research and Applications, Advanced Design, Production and Management Systems* (J. Cha et al, editors), AA. Balkema Publishers, Lisse, Portugal, 755-760.

Kumagai J. (2002). Talk to the machine, *IEEE Spectrum Magazine Special R&D Report on Leading Edge Technologies*, September 2002, 60-64.

Lai J. and Yankelovich, N. (2000). Conversational speech interfaces, in *The Human Computer Interaction Handbook* (Julie A. Jacko and Andrew Sears, editors), Lawrence Erlbaum Associates, Publishers, New York, 698-713.

Meissner A., Mathes I., Baxavanaki L., Dore G. and Branki C. (2002). The COSMOS integrated IT solution at railway and motorway construction sites - a case study, *Proceedings of the Conference on eWork and eBusiness in AEC* (Turk and Scherer, editors), Swets & Zietilinger, Lisse, 623-626.

Menzel K., Eisenblatter K., Keller M. and Scherer R.J. (2002). Context-sensitive process and data management on mobile devices, *Proceedings of the Conference on eWork and eBusiness in AEC* (Turk and Scherer, editors), Swets & Zietilinger, Lisse, 627-634.

Moraes. (2002). VoiceXML, CCXML, SALT. Architectural tools for enabling speech applications, *XML Journal*, Sept. 2002, 30-25.

Mrawira D., Rankin J. and Nunoo C. (2002). Web-based tool in project quality management, *Proceedings of the First International Conference on Construction in the 21st Century*, Miami, Florida, 959-965.

Myers B.A. and Beigl M. (2003). Handheld computing, *Computer*, September 2003, Vol. 36, No. 9, 27-30.

O'Reilly T. D., Waugh L. M., Kondratova I. L. and Lumsden J. (2003). Categorically speaking: Reflecting AEC/FM participants' requirements in groupware, *5th Construction Speciality Conference of the Canadian Society for Civil Engineers*, Moncton, NB, Canada, 4-7 June 2003, NRC 45833, 10 pp.

Rankin J. (2002). Information mobility for the construction industry, in Integrated Technologies for Construction, *Canadian Civil Engineer Spring issue*, 2002.

Rebolj D., Cus-Babic N., Tibault A., Magdic A., and Rodosavljevic M. (2002). Mobile product models, *Proceedings of the Conference on eWork and eBusiness in AEC* (Turk and Scherer, editors), Swets & Zietilinger, Lisse, 637-638.

Rivard H. (2000). A survey on the impact of information technology on the Canadian Architecture, Engineering and Construction industry, *ITcon* Vol. 5, http://www.itcon.org/

Russel A. and Froese T. (1997). Challenges and a vision for computer-integrated management systems for medium-sized contractors, *Canadian Journal of Civil Engineering*, 24, 180-190.

Srinivasan S. and Brown E. (2002). Is speech recognition becoming mainstream? *Computer*, April 2002, 38-41.

W3C. (2004). Voice Browser Activity - Voice enabling the Web!, http://www.w3.org/Voice [Last accessed April 2004].

Shiratuddin M.F., Perdomo J. L., and Thabet W. (2002). 3D visualization using the Pocket PC, *Proceedings of the Conference on eWork and eBusiness in AEC* (Turk and Scherer, editors), Swets and Zietilinger, Lisse, 639-644.

Weinschenk S. and Barker D.T. (2000). *Designing effective speech interfaces,* John Wiley & Sons, Inc., New York.