Developing a Service Robot for a Children's Library: A Design-Based Research Approach

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Understanding book-locating behavior in libraries is important and leads to more effective services that support patrons throughout the book-locating process. This study adopted a design-based approach to incorporate robotic assistance in investigating the book-locating behaviors of child patrons, and developed a service robot for child patrons in library settings. We describe the iterative cycles and process to develop a robot to assist with locating resources in libraries. Stakeholders, including child patrons and librarians, were consulted about their needs, preferences, and performance in locating library resources with robotic assistance. Their needs were analyzed and incorporated into the design of the library robot to provide comprehensive support. The results of the study suggest that the library robot was effective as a mobile and humanoid service agent for providing motivation and knowledgeable guidance to help child patrons in the initially complicated sequence of locating resources.

Introduction

The library, as an institution striving to provide diverse and organized information resources, is responsible for meeting the varied information needs of all types of patrons. To complete its mission, numerous resources are organized according to classification schemes and cataloging rules in advance of dissemination for public use. Because of the complex technical steps of managing the resources, there are various levels of tasks for end users. It is common for patrons in a physical library environment to go through multiple procedures, such as searching and identifying available resources via the open public access catalog, noting the call number, following the signs in the library space, and navigating between shelves to find the desired material. The degree of accessibility might be acceptable for adults, but it still could be improved (Agosto, 2007). However, patrons with different physical and cognitive abilities, such as children (Lushington, 2008; Schacter, Chung, & Dorr, 1998), the elderly (Joseph, 2006), and the visually impaired (Kinnell, Yu, & Creaser, 2000), may find it extremely frustrating to try to find information and locate resources in a library (Bosman & Rusinek, 1997; Ranford, 1993).

To cope with the patrons' frustration and failure, considerable efforts have been made to assist patrons in accessing resources in physical library environments. In addition to improving the spatial design and arrangement of signs, maps, and guidance (Joseph, 2006; Lushington, 2008), University of California Libraries (University of California Libraries Bibliographical Services Task Force, 2005) redesigned the library catalog to make accessing resources more

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efficient, and public children's libraries have introduced alternative categorizing systems using color tags (Taipei Public Library, 2011) that are attached to the shelves and books so that child patrons can identify and locate the resources quickly and intuitively. The major deficiencies of these practices are that the solutions address mostly partial or single aspects of the patrons' accessibility problems, without overhauling the resource-locating behavior in general. Moreover, these services, which are often in a fixed position, fail to provide simultaneous and customized assistance for individual patrons in locating books, so patrons compete for the limited amount of human assistance that librarians can provide, or even worse, they abandon their searches altogether. Although these difficulties have been addressed, few empirical studies have explored resource-locating behaviors in a physical library environment, despite its direct impact on patrons' access to information materials. Occasioned by the aforementioned issues, this study addresses patrons' difficulties in locating resources in libraries from the perspective of performance support with thorough task analysis by formative assessment to facilitate and respond comprehensively to patrons' needs.

From the perspective of technology and technical services, the foremost issue within the realm of library automation is resource discovery. In the past few decades, computational tools have increasingly been adopted and incorporated into library practice, and many libraries have been partially or totally automated. Systems have been developed to serve different purposes, covering everything from in-house operations to reference services in various formats disseminated over various devices. Robot applications to automate the service process facilitate acquisition, cataloguing, and circulation (Prats, Martinez, Sanz, & Pobil, 2008). Recently, more integrative systems that connect information platforms have been developed. Developments such as Kim, Ohara, Kitagaki, Ohba, and Sugawara's work (2008) coordinate robot arms, radiofrequency identification (RFID) tags and intelligent bookshelves to return books automatically. Similar applications use robots to help patrons with physical difficulties to retrieve library resources (Behan & O'Keeffe, 2008; Mikawa, Morimoto, & Tanaka, 2010). To complement these physical tasks, the possibility of using robotic assistance to support users' higher-order cognitive performance has turned researchers' attention to social and service robotics. For instance, robot applications to support children learning in formal and informal educational contexts are being developed (Kanda, Hirano, Eaton, & Ishiguro, 2004; Saerbeck, Schut, Bartneck, & Janse, 2010; Shiomi, Kanda, Ishiguro, & Hagita, 2007). Kiesler and Hinds (2004) also highlighted the possibilities of using service robots to facilitate patrons' communications and higher-order cognitive interactions in libraries.

However, the development of robots involves technical and service designs, and such designs require extensive interdisciplinary efforts at both the research and practice levels. Design-based research, which is widely accepted in educational research, provides a framework to systematically study a complex phenomenon in an authentic context of the practices, with the aim of producing research results that contribute to concrete artifacts and theory (Barab & Squire, 2004). Unlike previous studies, which provided evaluations of particular artifacts, the research on design contributes to the body of knowledge and is communicated both to the scientific community and to communities of practice (The Design-Based Research Collective, 2003). To achieve a better design for automated resource location services in libraries, this study involved a collaborative endeavor between professionals in reader service, information design, ergonomics, and robotics to design a service robot for child patrons in library settings. The iterative cycles and process to develop a children's library robot to assist with locating resources in libraries are described. The needs, preferences, and performances of both the child patrons and the librarians were evaluated and considered in the design of the library robot to provide comprehensive support.

Child Patrons and Locating Books in a Library

For many public libraries, child patrons, from toddlers to young adults, are major users of the library space and services (Brown, 2001; Walter, 2003), and they regard the library space as a familiar and favorable place to access information. Child patrons come to libraries for a variety of activities employing library collections and services. A user survey from public libraries in Taiwan, showed that school children 7 to 12 years of age are major users of library resources. This age group has a rapidly growing book-lending rate and an average of two visits per week (Taipei Public Library, 2011). In school libraries, during teaching and library instruction activities, children visit libraries more frequently. However, this significant population has not gained equal attention in academic research on library practices (Walter, 2001).

Child patrons often encounter difficulties when accessing materials in libraries due to their limited spatial skills and knowledge of the rules of library-information organization (Eaton, 1991; Harris & McKenzie, 2004). According to Eaton's (1991) study, elementary school children spent an average of 12 minutes to complete book-locating tasks, which was much slower than the average 6.5 minutes of older patrons. Traditional methods to cope with book-locating problems include designing library spaces and signage systems, such as maps and directories of the library space (Beneicke, Biesek, & Brandon, 2003). Library users are taught library knowledge so that they can track references to bookshelves. Other library practices use improved graphical catalogs and interfaces to cope with the difficulties children have when searching in typical keyword online public access catalogue (OPAC) systems (Bilal & Bachir, 2007; Hutchinson, Druin, & Bederson, 2007).

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However, child patrons actually prefer direct and social search strategies, such as going directly to the shelves to find books or asking a friend or a librarian for help (Borgman, Walter, & Hirsh, 1996). Facilities such as redesigned bookshelves and color guidance often fail to help patrons to locate resources in libraries due to an inappropriate environmental setting or insufficient spatial guidance (Li & Klippel, 2012). In fact, these time-consuming interventions interrupt the overall resource discovery and locating experiences that children enjoy in libraries, and the inconvenience of accessing the desired resource may lower motivation and leave information needs unfulfilled (Beck, 1996; Beneicke et al., 2003; Bosman & Rusinek, 1997). A systematic and consistent organization of spaces is essential to helping both first-time and experienced patrons to effectively locate the desired resource (Eaton, 1991; Li & Klippel, 2012; Mandel, 2011). Child patrons seek help from human librarians on finding basic and routine information, such as the location, title and call number of a book, not only because they prefer human help (Borgman, Hirsh, Walter, & Gallagher, 1995), but also because the fragmental spatial design fails to guide them through the book-locating tasks (Piper, Palmer, & Xie, 2009). Given the challenges imposed by the signage system, it is necessary to develop a way to provide automated services for child patrons to help them bridge the gap between the catalog and the desired materials.

Robots and Library Automated Services

Research in library automation has a long history of applying robotic assistance in book cataloguing, retrieval, and return (Kim, Ohara, Kitagaki, Ohba, & Sugawara, 2008; Morales, Prats, Sanz, & Pobil, 2007). These studies focused on overcoming technical problems by adopting industrial robots at fixed locations in the library. Mobile robots (Braunl, 2006; Dudek & Jenkin, 2000), which feature both autonomy and the ability to perceive and react to the environment, have only recently attracted much attention in libraries. Some academic libraries are incorporating mobile robots into the service process, using them to guide students to the proper shelf (Hahn, Twidale, Gutierrez, & Farivar, 2010; Meere, Ganchev, O'Droma, O'hAodha, & Stojanov, 2010); however, few applications of service robots, of the kind educational research has focused on (Chang, Lee, Chao, Wang, & Chen, 2010; Lin, Liu, Chang, & Yeh, 2009; Woods, Dautenhahn, & Schulz, 2004), have been used in library science and practice. These studies, albeit lacking specific contexts and environmental settings, have suggested a general preference for the robot as an appropriate agent to provide learning guidance and engage children in learning activities.

In addition to the appearance and guidance patterns, which are the most frequent focuses of previous studies (Kiesler & Goetz, 2002; Mikawa et al., 2010; Saygin, Chaminade, Ishiguro, Driver, & Frith, 2011; Woods et al., 2004), it is necessary to systematically involve child patrons in any exploration of better robot design to facilitate resource-locating tasks in libraries (Anderson et al., 2009; Dresang, 2005; Druin, 2002; Guha, Druin, & Fails, 2011; Mazzone, Read, & Beale, 2008). In this study, the form of robotic assistance for resource locating services is taken into systematic consideration.

Method

This study adopted design-based research (Barab & Squire, 2004; Sandoval & Bell, 2004) as the method to approach the relatively new concept of producing a library service robot for child patrons. The focus of the study is the evolution of the library robot as a design artifact through iterative processes to determine both the theoretical and practical implications of the design of library service robots. Children's book-locating activities assisted by the library robot were investigated, and users' perceptions and preferences toward the robotic assistance were subjected to formative assessment, to examine theoretical propositions concerning book-locating services and human-robot interactions in the design of a new library environment supported by robots. The opinions of stakeholders, including library users, or child patrons, and field experts, or librarians and service providers, were collected and incorporated into iterative evaluations to provide insights into the design.

Research Design

The library robot was investigated in complex real-life settings involving multiple variables, and various aspects of the design were refined using design-based research. Two design cycles were conducted in this study. As shown in Figure 1, the theoretical conjectures of the first cycle were formed according to the results of interviews with the initial user group, which included librarians, children, and parents.

In two iterations, successive refinements of design, perception, analysis, and redesign were applied. The first iteration focused on identifying problems for investigation in the area of children's library experiences supported by a robot. Stakeholders' views about the appearance and tasks of a library robot for book locating were investigated. The second iteration focused on the implementation of a robot for book locating in children's libraries and investigated stakeholders' feedback on the robotic book-locating assistance. The major users of the study included child patrons, parents, and librarians.

Participants Recruitment Strategies

This study adopted purposeful and convenience sampling methods to recruit stakeholders, including child patrons, librarians, and parents, who were involved in library services. In each of the phased objectives of each design cycle, different stakeholders' opinions were emphasized to provide essential information to improve the design. In the first iteration, the major users of library resources, child patrons who visited a local library and their parents, were recruited to participate in the study. They were interviewed to obtain their impressions and expectations for use in developing the form-study prototype of the library robot. For decisions on the functions and services of a library robot, professional users' opinions were collected from the librarians in a training workshop related to library services. In the second iteration, to verify the appearance, functions, and services of the robot design, a functional working prototype was developed and presented for formative assessment in an authentic context of a children's library by target users as confirmation testing.

Procedures

The procedures of the designed-based research process of this study are illustrated as follows.

The first iteration. The first iteration included the following steps:

1. Needs assessment: In the first iteration, the needs of the users were assessed by observations and interviews of the library users in a real-life setting of a public library for 2 weeks.
2. Theoretical conjectures: Theoretical propositions of human–robot interactions (HRI) and library services were considered in interpreting the library users' needs regarding the appearance of the robot and services.
3. Prototype design: A form-study prototype of the library robot, complete in both appearance and mobility, was developed according to the library users' needs and the theoretical conjectures.
4. Librarian evaluation: The form-study prototype was presented to the professional user group, and then a questionnaire on service evaluation was distributed. The librarians were asked to identify the critical functions of a library robot that would provide important additions to library practices and instruction.

Design Cycle I was based on collaborative development of the interventions with solutions and guiding designs, which were tested by librarians, parents, and child patrons who participated in the study. The service functions and the physical characteristics of the robot became clearer in this stage. The results of the evaluation were used to refine the initial conjectures and thus drove the second cycle of design.

The second iteration. The second iteration included the following steps:

1. Refined theoretical conjectures: In the second iteration, the refined theoretical conjectures of HRI and the corresponding service processes were used to develop a library robot, with specific reference to children's library literacy and cognitive development to fine tune the presentation of information by the robot.
2. Robot development: The form-study prototype developed in the first design cycle was further equipped with the necessary mechanisms and applications for book locating to make a functional working prototype. The working prototype was then implemented in the authentic context of a children's library.
3. Confirmation test: Formative assessment was conducted with real users having different perspectives in a genuine library context. Their activities were documented, investigated, and reflected upon to identify success and failures and to plan further improvements.

During the second iteration, the focus of the formative assessment was on the service processes and guidance styles of the library robot. In addition, the physical characteristics and functions of the robot were altered, and the development of the library robot for child patrons was completed.

Measurements

Needs assessment interviews. For needs assessment interviews, semistructured interview guidelines were developed to investigate child patrons' preferences for the appearance of the robot and its characteristics, desired functions, roles, and personality. To gain a comprehensive understanding of the ordinary resource locating behaviors of child patrons, the guidelines included questions about library experience, such as (a) how much time they had spent in the library over the past month, (b) why they visited the library, (c) what their

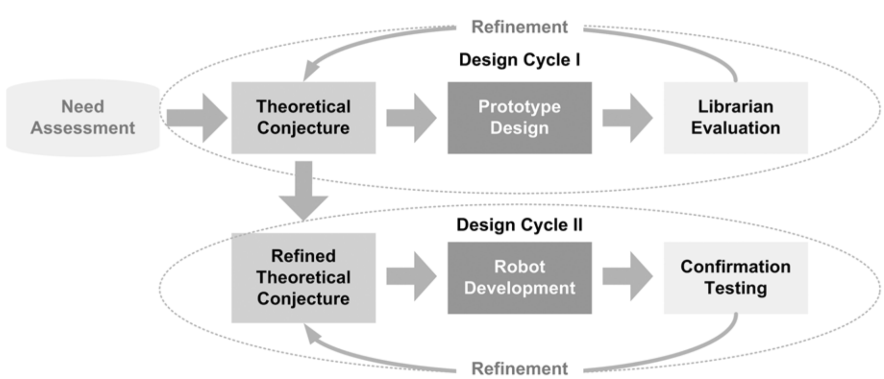

FIG. 1. Design-based research process in this study.

general impressions of the library were, and (d) whether the patrons requested assistance from librarians. For the appearance of the robot, a semantic differential scale was developed with nine bipolar pairs of humanlike and machinelike features based on human–robot interaction studies (Goetz, Kiesler, & Powers, 2003). To collect feedback from the children, the semantic differential scale was presented on a set of picture cards for better comprehension. The results were recorded and transcribed for further analysis.

Library-service evaluation. The library-service-evaluation questionnaire was composed of three parts: the perceived necessity of robot services for child patrons, the preferences for the appearance and physical features, and the form of robotic resource-locating services. From previous studies and local statistics about children's usage of public libraries (Child Welfare League Foundation R&D Division, 2005; Taipei Public Library, 2011), a category of child-readers' services, including popular services such as book borrowing, storytelling, and reference services, was derived. Each item of the questionnaire was evaluated on a 5-point scale (1–5), and the questionnaire had acceptable internal consistency (Cronbach's $\alpha = .82$) in general. The data were collected and analyzed to confirm the necessities, functions, and patterns of the library robot from the perspectives of service providers to verify the quality of the overall service process.

Formative assessment and behavioral log. Formative assessment was conducted to collect feedback from the representative users for further design considerations. The questionnaire contained critical elements of the robot's usability, including speed of motion, detection distance of the robot, tone and pace of speech, and height of the adjustable display to collect different perspectives of real users, to fine tune the service process of the library robot. The overall process was observed and recorded in behavioral logs to be further investigated in a following interview.

TABLE 1. Preferences for a library robot's appearance and characteristics.

Variable		Frequency	Percentage (%)
Age	Child	7	64
	Adult	4	46
Gender	Male	7	64
	Female	4	36
Height	As tall as me	8	73
	As tall as adults	2	18
	Shorter than me	1	9
Image	Toy	7	64
	Pet	4	36
Humanoid	Not humanlike	6	55
	Humanlike	5	45
Face	Without face	10	91
	With face	1	9
Computer screen	With computer screen	9	82
	Without computer screen	2	18
Mobility	Mobile	8	73
	Immobile	3	27
Motion facilities	Wheels	7	64
	Feet	4	36
Arm	With arms	10	91
	Without arms	1	9
Finger	With fingers	9	82
	Without fingers	2	18
Texture	Hard	7	64
	Soft	4	36
Touch	Cold	8	73
	Warm	3	27

Results and Discussion

Users' Needs for Library Robots

For this study, 11 children and 10 adult patrons who visited the library to borrow paper books were interviewed, which was consistent with a previous local survey (National Central Library, 2010) and also a foreign study (Lushington, 2008). Only children in the third grade and above were recruited for this study, for they were beginning to learn sentence making and composition in Chinese, which marks a turning point for the needs and capabilities of utilizing library resources (Taipei Public Library, 2011). Among them, six child–parent groups were regular visitors on a weekly basis, and the child patrons often requested book-locating assistance from the librarians or their parents.

In terms of the appearance of the library robot, child participants generally preferred a toylike, mobile robot of a similar age and height to themselves, as demonstrated by the interview results shown in Table 1. They expected robots to have human features, such as arms (91%) and fingers (82%), and to retain some features of a machine, such as a hard (64%) and cool (73%) texture, a computer screen (82%), and wheels (64%). Although the child participants did not identify facial features as important unlike in a previous study (Walters, Syrdal, Dautenhahn, Te Boekhorst, & Koay, 2008), the findings supported robot studies that found the exterior design should be more machinelike and cartoonlike, rather than humanlike (Kiesler & Goetz, 2002; Lin et al., 2009; Saygin, Chaminade, Ishiguro, Driver, & Frith, 2011; Woods et al., 2004).

In terms of the functions, roles, and personality of the library robot, 82% of participants reported that book-locating and borrowing functions were necessary, and 55% of them desired a material retrieval service. Social functions were popular among children, with 90% reporting playing and 72% reporting talking as necessary functions of the library robot. In addition, storytelling was also mentioned as a desired function by 55% of the participants (see Table 2). The desired functions further corresponded to the anticipated role of the robot, with four children preferring a librarian role to assist them in searching for and locating books, while another four children expected the robot to act like a teacher and tell them stories.

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TABLE 2. Expected functions, roles, and personality of a children's library robot.

Variables		Frequency	Percentage (%)
Functions	Playing	10	90
	Book finding	9	82
	Book borrowing	9	82
	Talking	8	73
	Book retrieving	6	55
	Story telling	6	55
	Time reminder	3	27
	Reading accompaniment	1	9
	Homework help	1	9
Role	Librarians	4	36
	Teachers	4	36
	Friends	2	18
	Adults	1	10
Personality	Cute	6	55
	Cool	5	45
Emotional expression	With emotional expression	6	55
	Without emotional expression	5	45

TABLE 3. Librarians' preferred services to be provided by the library for child patrons.

Service	*M*	*SD*
Story telling	4.50	0.99
Reading companion	4.45	0.93
Reading aloud books	4.40	1.03
Safety management	4.40	0.80
Book returning	4.04	1.13
Book borrowing	3.93	1.02
Reference service	3.40	1.12
Information retrieval	3.22	1.38
Current awareness service	3.18	1.23
Information referral	3.00	1.21

Besides cognitive support, the child participants mentioned that emotional support might be important. All child participants agreed that the robot should be friendly; along with their preference for machinelike features, the findings echoed Woods (2006) study of children's perceptions of the appearance of robots, that the machinelike features of robots were perceived as friendlier than humanoid ones. However, whether the robot should express its feelings remained undecided in this assessment, with half of the participants agreeing to the idea and half opposing it.

Moreover, the findings in this step echoed the need to provide resource-locating assistance, as stressed by previous studies (Eaton, 1991; Harris & McKenzie, 2004; Li & Klippel, 2012; Walter, 2003). For the library practices that engaged the robotic assistant, the results supported the idea of involving robots in library instruction and readers services. Like human librarians, the library service robot was capable of providing social and instructive guidance. Furthermore, the library robot was connected with and supported by the library information systems and databases to provide real-time, precise, and extensive information beyond human capability. By connecting electronic resources and databases with the current robotic guidance, it was possible to provide comprehensive and extensive services, such as book recommendations and reading at home.

Design of Form-Study Prototypes

Based on the results of the needs assessment, three form-study prototypes of robots as tall as an average elementary school student (Ministry of Education, 2011) were sketched for further evaluation. These form-study prototypes shared common features of appearance, height, and texture in response to child patrons' expectations of machinelike features. To balance the preferred hard/cool texture with the highlighted characteristic of friendliness, a hard metal texture with bright colors was used. The robots, as the child participants expected, appeared toylike rather than android, and all were equipped with wheels and displays to provide mobility and visual feedback.

With reference to the top three requirements that child participants expected, namely, resource locating, companionship, and storytelling, the three form-study prototypes were distinguished by the key services they provided. The first prototype provided resource-locating services by recognizing the spatial, resource, and user information of a library to help the child patrons locate the books they sought and to recommend reading materials for them. The second prototype served as a partner that accompanied children in reading with an enhanced speech interface to provide storytelling and reminding services. The third prototype developed in this study simulated a peer playmate for a larger group of child patrons, focusing on the library services for school-aged children to facilitate their collaboration in subjective inquiries and studies. It was critical to separate the different key services provided by each robot in this study, for such separation helped characterize the robot, centralize the functionalities, and coordinate child patrons' tasks effectively, in case the different flows across various library services might confuse them.

Only one form-study prototype was selected for further development as a working prototype with full functionality due to considerations of the research purposes and costs. With the child participants' emphasis on resource locating, and the design considerations provided by previous studies on library robots (Behan & O'Keeffe, 2008; Mikawa, Morimoto, & Tanaka, 2010; Prats et al., 2008), the resource-locating prototype was selected as the first prototype to be further engineered with the desired functions.

Librarians' Expectations of the Library Robots

In total, 48 librarians participated in the evaluation. As shown in Table 3, among the resource-locating related services, they rated book returning (mean $[M] = 4.04$), book borrowing ($M = 3.93$), and reference services ($M = 3.40$) as

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TABLE 4. Necessary characteristics of the library robot perceived by librarians.

Characteristic	Frequency	Percentage (%)
Show the map of the library	48	100
Show the map of the bookshelves	48	100
Be able to speak	48	100
Have a humanlike voice	48	100
Recognize the speakers	48	100
Recognize the emotions of speakers	47	98
Recognize the locations of speakers	46	96
Have a barcode scanner	46	96

TABLE 5. Preferences of librarians for the appearance and characteristics of the library robot.

Variable		Frequency	Percentage (%)
Gender	Female	30	91
	Male	3	9
Character	Cartoonlike	36	84
	Humanoid	7	16
Face	With face	23	53
	Without face	20	47
Computer screen	With computer screen	42	91
	Without computer screen	4	9
Means of locomotion	Wheels	33	75
	Feet	11	25
Arms	With arms	38	90
	Without arms	4	10
Palms and fingers	With palms	27	61
	Without fingers	17	39
Texture	Soft	29	83
	Hard	6	17
Emotional expression	With emotional expression	18	45
	Without emotional expression	22	55

important services to be provided by the library robot for child patrons. Additionally, the management issue of safety ($M = 4.40$) was specifically emphasized by the librarians; they expected that the library robots would help monitor the patrons and keep the librarians informed.

The resource-locating services that the librarians preferred that the library robot provide were further explored, and high consensus was reached. All librarian participants agreed that the robot should show a map of the library space and bookshelves, and 98% of these participants held the opinion that the robot should speak to the patrons in a humanlike voice and be able to recognize the location, words, and emotions of patrons. Barcode scanners were also considered necessary to enable the robot to provide services (Table 4).

As shown in Table 5, the views of the 48 librarians resembled those of the child patrons. The librarians expected the robot to be a cartoonlike character (84%) without a face (47%), and to be equipped with a computer screen (91%), arms (90%), and wheels (75%). However, their opinions differed on texture due to safety considerations. Because many librarians perceived the library robot to be female (91%), they preferred a soft texture (83%) rather than a hard and cool one. The librarians did not expect the robot to perform delicate tasks, so fingers were regarded as less necessary (39%), and they rated emotional expressions (45%) lower than the child patrons did.

One point that is worthy of note is that the librarian participants' preferences for social functions over guidance differed from those of the child participants, who focused on purposeful resource-locating tasks. In terms of the trust in the robot (Adams, Bruyn, Houde, & Angelopoulos, 2003), child participants showed greater confidence in the robots' reliability and integrity than the librarians did. The child patrons who participated in this study expressed considerable interest in visiting the library in the presence of the library robot because, in their opinion, the robot seemed omniscient and could lead them to any item in the library (C3B, C2G, C11G). On the other hand, the librarians valued the librarian–user conversation and felt that reading and library instruction should not be ignored in design considerations.

The implementation of the human–robot interface was an iterative process that began with defining the problems, including which library activities and which users' needs had to be addressed. From the findings of the first iteration, the appearance, major tasks, and features of a library robot were confirmed by the consensus of various stakeholders. The presence of the library robot was very much accepted by all participants in the first iteration. It was inferred that because the few librarians on duty were often occupied with serving other users, the child patrons frequently experienced frustration, which explained both patrons' and librarians' high hopes for a robotic rather than a computer interface.

Refinement of the Library Robot Design

Robot appearance and characteristics. The consensus among child patrons and librarians on the needs assessment and library services supported and validated the cartoonish design, the mobility, and the visual feedback. However, the conflicting expectations regarding textures revealed a significant issue of safety management. While minor conflicts of preferences, such as gender and facial features, were settled by following the children's opinions, the librarians' emphasis on soft textures was examined carefully because it reflected a desire to prevent injuries. To prevent injuries during accidental collisions, soft, brightly colored cushions were added to all angles of the exterior of the robot (Table 6).

The library robot was developed as a toylike character as tall as the average third-grade student. The aluminum-skeletoned Z-shaped exterior, inspired by the library book cart as a machinelike metaphor, was intended to incorporate the idea of transportation and books in libraries to give users an impression of mobility and book finding. Minimized facial features equipped with facilities including a camera,

TABLE 6. Preferences of child patrons and librarians for the appearance and characteristics of the library robot.

Variable		Children	Librarian
Gender	Female		✓
	Male	✓	
Character	Cartoonlike	✓	✓
	Humanoid		
Face	With face		✓
	Without face	✓	
Computer screen	With computer screen	✓	✓
	Without computer screen		
Means of locomotion	Wheels	✓	✓
	Feet		
Arms	With arms	✓	✓
	Without arms		
Texture	Soft		✓
	Hard	✓	

TABLE 7. The specifications of Book Smile.

Size	50 cm × 70 cm × 130 cm
Weight	60 kg
Skeleton	Aluminum
Driving type	Two-wheel differential type
Driving motor	DC servo motor
Max. speed	1 m/s
Batteries	16 V Li-ion battery
Computers	Industry computer and Mac mini
Display	8.9′ panel and 12′ touch panel
Camera	Monocular camera and stereo
Laser	SICK and Hokuyo
Continuous operation time	0.5–2 hours

projector, and barcode reader were placed on the slope of the Z shape to add a human touch to the machine. The mouth of the robot was made of a soft rubber material that analogically reacted to weight and pressure. When a child patron found a book and put it on the robot's mouth, it would analogically create a smile on its face, expressing friendliness, and would naturally lead the children to the right position to interact with the robot. The library robot was named "Book Smile" in accordance with the design intention of enhancing and leveraging children's preferences for a robot that was machinelike with a humanlike personality and behavior by tailoring the human manipulations into computer interfaces seamlessly.

In comparison to the existing computer interfaces common in libraries for resource locating, the findings of the study suggested that robotic interfaces were more feasible because child participants perceived the library robot as a service provider instead of an information system or companion. The child users projected their expectations of human librarians onto the robots and expected them to have the intelligence and professional skills to help people. The robotic appearance and accompaniment of the library robot appealed to the children by transforming the hard messages, such as catalogues and call numbers, into soft guidance to instruct the child patrons more intuitively, thus decreasing the frustration caused by their limited spatial skills and knowledge of the rules of library information organization.

Robot Functions and Services

The working prototype, Book Smile, with a functional appearance to provide resource-locating services was equipped with laser and image sensors and a localization system developed in-house by the researchers (Tseng et al., 2011). The specifications of Book Smile are shown in Table 7. Book Smile was capable of human sensing and context-aware navigation. It displayed a map of the library and bookshelves to guide patrons, spoke in a human voice, and scanned barcodes for book borrowing.

Using its localization system, the robot was able to recognize its location in real time and knew which course it should plot after receiving a request from a user. The laser sensors with human-sensitive functions allowed Book Smile to recognize a patron and avoid obstacles along its path to prevent collisions with bookshelves and library patrons. The map of the library, which was learned by the robot in real time, was synchronously interpreted and transformed into speech and visual guidance shown on the top display. A human voice provided the speech interface, in accordance with the librarians' opinions, and the child patrons could activate the guidance system simply by touching the panel on the top of the robot.

The algorithm examined and verified by the librarians was performed by Book Smile as follows:

1. Recommending a book: Given no pre-specified search, the robot actively recommended books on its display graphically and verbally, and asked the patron to select one of them by touching the display with his or her fingers.
2. Locating the book: As soon as the patron selected the book and pressed the button "Take me to the book" on the graphical interface (see Figure 2), the robot articulated the location of the book in the library and simultaneously displayed a library map and the location of the bookshelf. The guidance was provided in synchronous narration with the corresponding visual information on the display.
3. Identifying the book: As the robot approached the bookshelf, the location of the book on the shelf was shown on the screen. Both text and graphic information about the book were shown on the display to help the user identify the resource he or she was seeking.
4. Obtaining the book: The robot articulated the location and instructed the patron to find the book on the shelf and put it on the "mouth" of the robot. Both the shelf and the book information remained on the display until the book was detected on the mouth to ensure that the desired material was successfully obtained. In cases of failure or delay, that is, if the book was not placed on the position within 5 minutes, the robot would remind the user and ask if the

FIG. 2. Prototype of the user interface.

current book was no longer expected. A "yes" response led to the first rule, and a "no" response led to the next rule.

5. Confirming closure: After obtaining the book, the patron was asked if any other books were desired; "yes" led to the first rule, and "no" led to the next rule.
6. Borrowing the book: The robot guided the patron back to the circulation desk to check out the book. On the way to the desk, the robot read an abstract of the selected book.

To confirm if the general rules adopted by the library robot suggested a correct and fluent sequence of resource-locating tasks for children, a formative assessment was then conducted.

Results of the Confirmation Test

The working prototype with complete functionality in terms of resource locating was presented to a group of users with a formative assessment in the actual setting of a children's library. The participants included a third grader, a preservice librarian, and a veteran librarian from a public library. The focus of the confirmation test was on the flow of resource locating provided by Book Smile. All three participants were tasked with finding and signing out an assigned book in the library with the assistance of the robot. From the preliminary findings, issues associated with the angle of the display, speed of movement, and guidance patterns that hindered the users' operations were raised, and corresponding modifications were made.

As shown in Figure 3, the display to provide visual feedback was redesigned to be flexibly tilted up to 30° to avoid problems with glare and was accordingly adaptable for children of different heights. The movable joint was covered with black mortar board, as shown in Figure 3, to maintain the consistency of its appearance. The speed of movement was also increased to match children's walking speed. The laser sensors would sense when the users fell behind by over 30 cm, at which point the robot would stop to wait and remind the user to follow it and keep the attention of the user. Additionally, a guidance pattern having a graphical interface and multiple human voice modes was adopted in response to the results of the confirmation test, which suggested that child patrons were highly attracted to the pictorial representation and a child's voice.

Conclusions

This study addressed child patrons' difficulties in locating resources in libraries. A thorough task analysis from the perspective of performance support was used to facilitate and respond comprehensively to patrons' needs. The study adopted the design-based research method and involved a collaborative endeavor between library science and engineering to design a service robot to help child patrons locate resources. The needs, preferences, and performances of both the children and the librarians were carefully examined with reference to theoretical and practical conjectures from existing research and observations in real settings to improve the design of the library robot. Task analysis and iterative cycles involving the stakeholders were used in the robot design.

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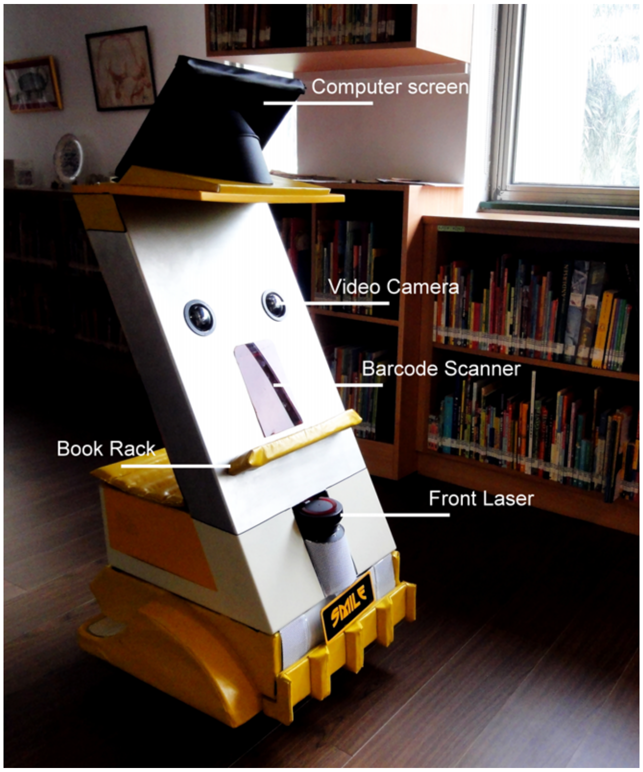

FIG. 3. Refined exterior of "Book Smile." [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Through two cycles of design and evaluation, a working prototype equipped with functional hardware and software that corresponded to the users' needs in terms of appearance and function was developed and tested in an actual library setting. The library robot developed in this study was perceived to be suitable for helping child patrons locate resources in a public library.

This study is distinct from previous studies of library robots (Behan & O'Keeffe, 2008; Mikawa et al., 2010) in that it incorporated and extended anthropomorphic features into the functions of the robot to provide instructive guidance. The intelligent service robot was able to meet child-patrons' preferences for social-search strategies and also librarians' expectations for a substitute agent. According to the findings, robotic assistance assured precision in locating a resource in the library, and it allowed individualized and adaptive services. The library robot connected the library resources with the child patrons, who were thus motivated to explore and enjoy the library.

These improvements in the services increased the motivation and interest of the child patrons to visit the library, meeting a clear need. A local census on children's libraries in Taiwan suggested that the major activity of child patrons in public libraries was to borrow and check out paper books. However, the same survey also reported a generally low rate of children visiting libraries due to insufficient motivation (Child Welfare League Foundation R&D Division, 2005). Without learners' motivation and engagement, advanced library instruction can hardly be expected to succeed (Hudson, McGowan, & Smith, 2011; Patrick, Mantzicopoulos, & Samarapungavan, 2009).

In addition to increasing motivation by raising interest, the robot librarian also removed a demotivational factor inherent in libraries by providing assistance when such assistance would otherwise have been unavailable. In general, when the librarians are occupied with other users, or are unfamiliar with the desired resource, child patrons often experience significant frustrations that diminish their motivation for further exploration. The robotic assistance provided by the prototype in this study incorporated multiple information systems and a friendly interface that effectively removed this inhibitor.

Methodologically, this study adopted design-based research that sought to increase the impact, transfer, and translation of robot research into improved library practices. Incorporating rapid prototyping techniques and the iterative cycles of design and observation during the construction of the library robot, this study included the design of interventions, which is theory-driven by iterations of design, performance, analysis, and redesign to allow refinement over time. By researching the design, this study contributed to the body of knowledge and was communicated to and assessed by the scientific communities of library, communication, and engineering science, and with communities of practice including the librarians and child patrons to overcome the insufficiencies of conventional designer-driven methods. This study focused on and was situated in an actual library context. The context provided not only an evaluation of the robot design, but also models and theoretical explanations that added to the children–robot interactions. Lastly, this study involved a collaborative partnership between researchers and practitioners to leverage the complexities of the culture, technology, objectives, and politics of an operating library system to effectively create and measure the impact of a library robot. The systematic approach of design-based research to include multiple stakeholders overcame the objectivity and bias that plagues many engineering projects, without sacrificing the comradeship and enthusiasm to actively support the intervention of a library robot.

Despite all the positive aspects, it is also necessary to consider the possible negative aspects of having a robot in the library. Although in this study, having a robot in a library was a great activator to draw children's attention, a library robot could also be a distraction if the children prefer to play with the robot instead of reading a book. In addition, if more child patrons are attracted to the individualized services that such a library robot provides, more library robots will be needed. Providing libraries with multiple robots could be challenging due to the currently high cost of robot development.

Finally, it should be noted that the study was limited by the current resources, including the accessibility to institutions and users, the system stability of the prototypes, and the overall small collections of children's books in Chinese

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(National Central Library, 2010). In the future, the effectiveness of robotic assistance will be evaluated through field testing on a larger scale involving more child patrons in natural settings. For the next iteration, theoretical propositions regarding the intellectual interactions between children and robots should be incorporated to further refine robotic guidance. Additionally, although the current study focused on robotic assistance with locating resources, robotic social companionship was also valued by the librarians in this study and is worthy of exploration in future studies.

This study contributes to the fields of research and practice through the empirical implementation and evaluation of a library service robot for a children's library. The results of the formative assessments provided feedback that was useful in improving the design iteratively, and the library robot met the child patrons' and librarians' needs and preferences for mobile and humanlike guidance. The objective of the current study was met by developing a fully functional prototype to help child patrons with the initially complicated sequence of locating resources in libraries.

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