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A methodological approach for designing and developing web-based inventories of mobile Assistive Technology applications

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Abstract Mobile technologies provide radical opportunities in the domain of Assistive Technologies (AT) for persons with disabilities and the elderly by facilitating them to access multimedia content and improve their social interaction. The search for mobile AT applications that meet specific user needs is not an easy task for the disabled users, their facilitators, and rehabilitation professionals, as the mobile app stores do not include a category for AT or a classification by disability. In this work, we first provide an analysis of the disabled users' needs along with the required mobile software adaptations in order to fulfill them. Then, we introduce a methodological approach for the design and development of web-based inventories which make the search and selection of AT apps simpler and efficient. This methodology has to main parts, first it is based on experts in an AT lab thoroughly testing each application, and second, the creation of a consistent and well-documented presentation of the information for each app. Finally, we present the mATHENA repository of free AT apps for mobile devices (smartphones and tablets), which has been created by following the suggested methodology for creating AT app inventories. Currently, mATHENA includes 420 free mobile AT applications, carefully selected from a total of 1100. The features of mATHENA are compared with the functionality and social interaction services of six other inventories for AT applications.

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1 Introduction

Computer-based Assistive Technology (AT) offers devices, tools, equipment, software, and services that help maintain, augment or improve the functional capabilities of the disabled and the elderly. In the last few decades, there is an increasing interest in the domain of AT. This interest comes out from the research institutes, the industry, the academia and a number of professionals, such as software engineers (mainly developers of human-computer interfaces, designers of websites, and web content providers), rehabilitation practitioners, therapists, and teachers in inclusive and special education [39]. The main forces that boost this interest origin on: i) the policy frameworks of the United Nations and the European Union, as well as the national legislations for the benefit of the disabled and their societal inclusion and participation [1, 7, 24, 25], and ii) the increasing demographic figures of the aging population, since the number of the disabled rises significantly for those above the age of 65 [23, 60, 61]. Recently, the field of AT underwent substantial progress, through emerging scientific and theoretical methods, advanced technologies, and novel application domains [59].

The developments in mobile technology, including the introduction of tablets and smartphones, yield radical opportunities in the domain of AT and create a novel impact on the participation of the disabled and the elderly in everyday life [19, 38, 44, 52] and particularly on the improvement of their social interaction and networking [20]. Besides, mobile AT apps can be used within a much broader scope. For example, research in the domain of Universal Design for Learning (UDL) has shown that mobile AT apps engage all students, including those with disabilities, in collaborative learning, reasoning, and problem-solving activities [10, 28, 35, 42].

Statistics [58] show that today's Android [29] and iOS [2] users have the possibility to choose between more than 3 million mobile apps. However, the mobile app stores do not include a category for AT or a classification by disability. Thus, the search process for mobile AT applications that fulfill specific user needs is not an easy task. All the target groups face difficulties: the end-users, their facilitators, as well as the rehabilitation professionals. In many cases, the users don't know the right keywords for searching in the app stores. Moreover, the description of an AT app does not always include the proper keywords corresponding to the terminology used by the end users. Even when they locate the AT app they are searching for, a number of questions arise concerning its functionality, compatibility, stability and reliability [34, 36, 37]. These questions can be safely answered only by a team of AT experts following appropriate evaluation methodologies [13, 68]. Furthermore, the description of the AT apps is not always consistent, as the fields included to describe each app as well as the amount of information provided in each field differ.

Dedicated AT online databases and inventories have been recently developed for the elderly [27], the visually impaired [32], the communication impaired [33, 44], and for medical applications [53]. We study and compare these online sources throughout this paper. All of these have been developed in an ad hoc approach without following a widely accepted methodology.

Our main scope in this paper is to propose a new methodological approach for the design and development of web-based inventories which will make the search and selection of AT apps simpler and efficient for end users. Moreover, our goal is to present concrete evaluation results of the introduced methodology by implementing and testing it in the mATHENA inventory.

In Section 2 we analyze the AT users' needs relative to mobile apps. Next, in Section 3 we review the existing inventories of mobile AT apps. In Section 4 we describe the methodological approach for the design and development of web-based inventories that aim to ease the search and selection of both free and commercial mobile AT applications. In Section 5 we present the results of the design and development of the mATHENA web-based inventory, along with a comparison of its functionality with the existing relative resources.

2 Users' needs

Disabled persons form the main target group for the mobile AT apps which can be classified in various categories. Different kinds of disabilities may lead to the need for special-purpose apps, which pertain to the same AT category. Mobile AT apps can facilitate the access to the mobile device itself, or help in other aspects of the disabled person's life, like access to online and electronic multimedia content, interpersonal communication, environmental control, education, entertainment, and everyday living.

We will briefly present the most important characteristics of the prevalent AT user groups, namely people with motor, visual, cognitive, speech, and hearing disabilities [65]. Then, we will provide a correlation of the disabled user needs with the required mobile software adaptations and applications.

2.1 Motor disabilities

Persons with motor disabilities include those with difficulties in moving, upper limp control and coordination, missing limbs, limitations of sensation, and so on [48]. Although some people with physical disabilities have no problem to access tablets and smartphones, there are people with motor limitations who face serious difficulties in using conventional mobile input devices such as touchscreens.

The most important need, particularly for those with upper-limb impairment, is to conduct the main tasks needed to operate a typical mobile devices' visual and touch interface: hold the device, see the screen, and touch the screen. In modern mobile operating systems, everything is done using these three actions. The fingers are used to point, select, type, scroll, enlarge, rotate, and perform all the gestures a multitouch interface supports. The hand is used to hold the device in the correct position; the arm brings the device to the correct place so that the user can see it and use it.

Often, people with motor disabilities, affecting their fingers, hands, or arms, are not able to use a standard handheld device by directly tapping its touchscreen; instead, they use specialized input devices, such as trackballs, a variety of switches, eye-tracking systems, head movement tracking, joysticks, touchpads and modified keyboards. In most cases, the AT hardware must be combined with appropriate AT software (e.g., scanning techniques, voice commands, on-screen keyboards, word prediction, click helpers, etc.).

2.2 Cognitive and speech disabilities

Almost 3 % of the general population faces interpersonal communication problems [9], due to severe speech or language impairments. Augmentative and Alternative Communication (AAC) could benefit almost all of them [31, 41]. Advanced computer-based AAC systems supplement or replace speech or writing for those with language impairments [6, 11, 18, 21, 26, 45, 46]. Those with a communication disability can be classified as persons who require: a) expressive language (usually due to severe motor problems that obstruct normal speech), alternative language (usually when they are language/cognitive impaired) or supportive language (usually because of speech delay or unintelligible speech) [12]. AAC systems rely on either written text or sets of graphic communication symbols for the language impaired.

Stand-alone dedicated AAC devices are expensive. On the other hand, a smartphone or a tablet equipped with a communication app is much cheaper and in most cases a lot more portable. The AAC app area for mobile devices is constantly growing, for both commercial and free software products.

2.3 Blindness and low vision

Blind users of mobile devices interact with the screen elements using multi-finger gestures [54] and a screen reader app, which sends the identified text to a text-to-speech app (software that dictates the text so the blind user can hear it trough speaker or headpiece) or a braille display device connected through Bluetooth (forms braille lines of text on the device that the blind user can feel with his/her fingers). Moreover, screen readers help the blind user to locate navigation elements, icons, and web links.

Nowadays, most of the smartphones or tablets come with a text-to-speech app preinstalled, such as VoiceOver in iOS devices [3] and TalkBack in Android [30]. The available gestures on mobile devices include a range of gestures, many of which offer far more functionality than the simple tap and swipe gestures used by most sighted users [55].

Having a camera on a mobile device can also be very useful for people with visual impairments. For example, a user with vision loss can take a photo of a text document using a smartphone or a tablet, and an Optical Character Recognition app can analyze it, and a text-to-speech app can afterwards read it aloud; apps exist that can also magnify the text document, or change the viewing conditions (e.g., contrast, colours, brightness) in order to facilitate reading for persons with low vision. There is also a range of identification apps that, for example, will recognize and speak aloud the colour of an object, the value of paper money, or the type of an object (based on its shape, logos or text printed on it).

2.4 Hearing loss

Persons who are deaf or hard-of-hearing have no problems seeing or touching the screen of a mobile device. They have difficulties with spoken communication and sounds. Moreover, those who have Sign Language as their first (native) language may face problems in the use of a natural language. Video-calling allows people with hearing loss to use sign language or lip-reading over the smartphone or tablet to communicate. Moreover, video-calling using mobile devices can be used in remote interpretation services of Sign Language. Both Short Message Service (SMS) and Multimedia Messaging Service (MMS) are used in mobile devices for non-voice communication by persons with hearing loss.

2.5 Correlation of user needs with mobile software adaptations

Table 1 (adapted and modified from [50]) presents an overview of the most important user needs in correlation with the mobile software adaptations, that can be made in order to meet the needs, for the following disabilities: B: Blindness, L: Low Vision, D: Deafness, H: Hard of Hearing, P: Physical Disabilities and C: Cognitive, Language, Learning Disabilities and Low Literacy. The classification of the needs includes: 1) reading aloud and highlighting, 2) reorganizing, simplifying and translating, 3) supplementing content, 4) audio enhancement, 5) adjustable or alternate input devices, 6) facilitating written communication, 7) error prevention and recovery, 8) preference and privacy features and 9) special or general.

One problem that AT users face is the high cost of AT software and hardware products. Even when cost is not an issue, for example when software is free of charge or inexpensive, the potential AT user comes across a second obstacle: the dispersion of the locations where these products can be found; information for each product is available on its own dedicated website, so there is no easy way to overview all available AT software as if they were in one place. Online AT software inventories and lists try to address these drawbacks. Other problems that may arise when a specific product is about to be selected include compatibility issues as well as the limited number of languages that are usually supported, in many cases the software is not compatible with the user's computer or operating system [22]. For non-English speaking users, finding an AT software that 'speaks' their own language is often a challenging task. Furthermore, there is no reassurance that an AT application has been tested by a specialist team in terms of usability and stability. Often, AT apps do not offer some warranty, support, or extensive documentation, so testing them before they are listed is an important issue.

3 Existing inventories for mobile AT apps

By the term AT inventories (or repositories) we denote websites that aim to list and inform potential users about AT apps' availability, features, and resources. They usually are dynamic websites, based on databases, which store and retrieve all fields and records that are presented. Below we present a review of the most important existing inventories dedicated to mobile AT applications, along with their main characteristics.

Special Needs Apps [16] currently lists 419 free or commercial applications for iOS and Android. For each application, a description is given, and users have the opportunity to download apps directly from the App Store [2] or Google Play [29]. Users can search for a specific application using three different ways: a) the general search field, using keywords, b) the category-based search (Speech & Language, Scheduling, Education, Behavior, Life Skills, Social Skills, Games and Communications), and c) through sorting the entire app list by choosing the sorting criteria: most popular, average rating, newest, price range. Furthermore, the inventory includes a rating system, a feedback (comments) field for members, screenshots and videos for each mobile AT app.

BridgingsApps [14] provides an inventory with 3254 mobile AT apps (free or commercial). It includes nine main filters for searching: 1) Keyword Search, 2) Skill Levels, 3) Mobile Devices, 4) Embedded Skills, 5) Independent Traits, 6) Assistive Traits, 7) Assistive/Independent, 8) iTunes Categories, 9) Android Market Categories. Moreover, there are more than 100 sub-filters for all nine filters, which users can apply in order to fine-tune their search, a facility that is rather complicated for the inexperienced user. For each application, there is a separate

Table 1 User needs related to mobile devices and multimedia content, related to indicative software adaptations in order to meet them (adapted and modified from [50]). Disabilities column coding: Blindness (B), Low Vision (L), Deafness (D), Hard of Hearing (H), Physical Disabilities (P), Cognitive, Language, Learning Disabilities & Low Literacy (C)

Needs	Software adaptations	Disabilities
Reading aloud & highlighting	Read entire text aloud	B, L, C, D, H
	Read words or blocks of text aloud when highlighted or clicked	L, C
	Highlight each word as it is read aloud	L, C
	Provide pronunciation help on-demand	C
	Allow the user to correct text-to-speech mispronunciations	B, L, C
	Use vocal characteristics to present visual formats	B, L, C
Reorganizing, simplifying, & translating	*Visual transformations*	
	Magnify, zoom in/out	L
	Adjust colors according to user settings	L, C
	Shift colors to make text and images visible with certain types of color blindness	L
	Adjust text font, including size and spacing	L, C
	Adjust contrast or use a high contrast mode	L, C
	Use a customized, alternate Cascade Style Sheet (CSS)	L, C
	Use special fonts to facilitate reading by people with Dyslexia	L, C
	Reorganizations	
	Reformat displayed text to facilitate reading	L, C
	Reformat web-page with a balanced depth & breadth of menus	B, C, P
	Create skip links ("skip to main content", etc.)	B, P
	Group links according to context	B, C, P
	Create consistency among web-pages, while maintaining distinguishable appearances of pages	B, L, C
	Other transformations	
	Prevent flashing to reduce risk of epileptic seizures and reduce distractions	L, C
	Transform content to conform to accessibility standards	ALL
	Translate and format text for Braille display	B
	Provide alternate simpler web browser	B, C
	Provide summarized content generated automatically	B, L, C
	Provide ability to pause, rewind, and replay multimedia	B, C
	Provide ability to extend or remove time limits on reading	B, L, C, P
	Provide ability to extend or remove time limits on completing an action (filling in a form, etc.)	B, L,C, P
	Sign language translation	
	Translate from sign language to text	D, H
	Translate from text to sign language	D, H
	Provide real-time translation of speech to sign language for live feeds, streaming audio and multimedia content	D, H
	Retrieve existing sign language multimedia	D, H
	Translation into a simpler form of the same language	
	Translate text into a simpler language	C
	Retrieve and link to existing simpler language version	C

Table 1 (continued)

Needs	Software adaptations	Disabilities
	Graphic translations	
	Translate text to symbols	C
	Translate text to pictures	C
	Convert emoticons to icons and set an alternate text label	B, C
Supplementing content	*Word level enhancements*	
	Retrieve a definition for a selected word from a glossary/online resource	C
	Retrieve a definition for a selected idiom	C
	Retrieve a definition for a selected abbreviation, acronym, or technical term	C
	Retrieve a definition for foreign language phrases	C
	Page & site level enhancements	
	Support collaborative third party markup for accessibility	ALL
	Provide descriptions of links	B, C
	Generate sitemaps	B, C
	Display breadcrumbs	B, C
	Integrated help & reminders	
	Provide cues and prompts to aid browsing	C
	Provide contextual help	C
	Offer real-time assistance	C
	Visual equivalents for audio	
	Generate or retrieve a text alternative for audio/multimedia content	D, H
	Provide visual alerts for system sounds	D, H
	Interactive transcript	D, H
	Image descriptions	
	Generate or retrieve text descriptions/tags for poorly labeled images	B, L
	Sonify videos or images to provide "synthetic vision" using audio	B
	Offer real-time assistance	C
Audio enhancement	Reduce/eliminate background noise	D, H
	Adjust pace of speech/audio	D, H, C
	Adjust volume and pitch	D, H, C
Adjustable or alternate input devices	*Keyboard settings*	
	Delay time before repeat	P
	Debounce time	P
	Ignore short key presses	P
	Keep modifier keys active until another key is pressed	P
	Alternate text entry methods	
	Keyboard input	B, P
	Voice input	B, P, C
	Alternate virtual / on-screen keyboard	P, C
	Make all functionality available with a limited number of input switches or a reduced keypad	P
	Accept Morse code inputs from screen tapping, mouse or another input device	P
	Accept symbol-based input	P, C

Table 1 (continued)

Needs	Software adaptations	Disabilities
	Allow input by gesture with any body part(s) (hand, facial, posture, etc.)	D, H, B
	Touchscreen settings	
	Tap pressure	P
	Double tap speed	P
	Visual feedback for tapping	P
	Vibration feedback for tapping	P
	Audio feedback for tapping	P
	Use multitouch gestures to perform commands or enter text	P
	Anti-tremor filtering	P
	Alternate pointing methods	
	Support head, or any body part -tracking input	P
	Support joystick input	P
	Support eye-tracking input	P
	Support switch input	P
	Alternate command	
	Allow control by gestures	P, B, C
	Command line interfaces	B
	Automation of Common Tasks	
	Provide customizable commands that perform actions with fewer key presses	P, C
	Provide Macros that replay a set of pre-recorded actions with a single key press	P, C
	Provide customizable shortcuts or gestures to help users jump to the content they need	P, C
Facilitating written communication	Automatically check spelling and grammar	C
	Assist with homophones	C
	Automatically predict/complete words and phrases	C
	Read letters and words aloud as they are typed	B, L, C
Error prevention & recovery	*General error prevention & recovery*	
	Help minimize errors	ALL
	Provide general strategies and contextual aid to safely recover from errors	ALL
	Safe internet usage	
	Assist in judging credibility and authenticity of sites	C
	Maintain a list of trusted sites	C
Preference & privacy features	Automatically determine and adjust settings	A
	Choose preferred features and adjust settings with a user-friendly feature wizard	ALL
	Provide settings and options that are easy to try out and modify	ALL
Special/general	*Virtual worlds & gaming*	
	Audio interpretation of visual content and actions	B, L
	Audio descriptions of objects in local area	B, L
	Provide the ability to discover relationships between items	B, L

Table 1 (continued)

Needs	Software adaptations	Disabilities
	Accessible authentication methods	
	Provide accessible CAPTCHAs to authenticate access to websites	B, L, C
	Enable secure access without a memorized password	C
	Real-time navigation	
	Provide GPS navigation/wayfinding features on mobile devices	B, L, C
	Context	
	Using context to modify, adjust, tune any and all of the above	ALL

web-page with a description written by AT reviewers, a rating system (0–5 star scale) and a URL for downloading.

AppleVis [4] inventory includes more than 2678 free of charge and commercial apps for iOS devices, specially designed for visually impaired people. The inventory provides an alphabetical list of applications. After selecting an application, the user can see the general description of the app, and can search for similar apps using the filters or using the "more like this" section. Moreover, there is a keyword search field and a field for user comments.

AppsforAAC [5] is a website that lists alphabetically 265 commercial or free applications in the domain of Augmentative and Alternative Communication (AAC) for Android and iOS devices. There are three different ways to search the inventory choosing: 1) device (iPad, iPhone, Android), 2) type of app (Access, Education Support, Eye Pointing, Language Development, Picture Exchange Communication System (PECS), Photo Story, Phrase Bank, Set Phrases, Symbol Grid System, Text To Speech, Word Prediction), and 3) price range. Each application has its own page with a description, a URL for downloading, a URL connecting with the developer's website, screenshots, a rating system and a field for user comments.

AssistIreland [17] provides a list of 71 iOS or Android, commercial or free, mobile applications for persons with disabilities and the elderly. Users can select apps according to five main classes of disability: Visual Impairment, Hearing Impairment, Communication difficulties, Alzheimer or dementia, Autism and other related disorders, Mobility difficulties. Users can choose between sub-categories that classify the applications taking into account the purpose of use. Unfortunately, there is no individual page for each application, no download URL, no URL of the developer, no rating system and no field for user comments.

LowVisionBureau [43] lists 326 iOS mobile apps for the visual impaired. Search is facilitated by selecting between 21 application classes: 1) Communication, 2) Education, 3) Entertainment, 4) Food and Drink, 5) Games, 6) GPS/Navigation, 7) Greeting Cards, 8) Health, 9) Magnification, 10) Music/Radio, 11) News, 12) Pets, 13) Photography, 14) Productivity, 15) Reading, 16) Social Network, 17) Sports, 18) Travel, 19) TV/Movies, 20) Utilities, 21) Voice Controlled. A team of experts is responsible for the selection and testing of each app. A small description and a download URL are included for each application.

Table 2 presents a comparison of the main features of the inventories mentioned above. All of them support both free and commercial apps for the iOS and the Android (except the AppleVis). The number of apps range from 71 to 3254. The searching filters vary from 1 to 9; half of them provide a user rating facility and only two allow user comments. Also, two of them are dedicated inventories, one for AAC users and the other for those with visual impairments.

Table 2 Main features of existing inventories for mobile AT applications. a: SpecialNeedsApps [16], b: BridgingApps [14], c: AppleVis [4], d: AppsforAAC [5], e: AssistIreland [17], f: LowVisionBureau [43]

	a	b	c	d	e	f
Number of apps	419	3254	2678	265	71	326
iOS	YES	YES	YES	YES	YES	YES
Android	YES	YES	NO	YES	YES	NO
Free	YES	YES	YES	YES	YES	YES
Commercial	YES	YES	YES	YES	YES	YES
Searching filters	3	9	3	3	5	1
User rating	YES	YES	NO	YES	NO	NO
User comments	YES	NO	NO	YES	NO	NO
Comments				AAC only		For the visual impaired only

4 Methodology

As we have described in the Introduction, it is crucial for an inventory of mobile AT applications:

- To be developed in a systematic way,
- To include apps after a selection and evaluation process, preferably conducted by experts in the field, and
- To provide a consistent description for all apps.

Following these principles, we propose the following six-step methodology for the design and development of functional and reliable inventories of mobile AT applications; the procedure of searching, installing, testing, documenting, and updating AT apps in a database-driven inventory (excluding the design and implementation of the website itself) is also illustrated in Fig. 1.

1. **Search and locate mobile AT apps.** Depending on the inventory scope, the exploration must cover either one or more mobile operating systems (iOS, Android, MS-Windows mobile). Moreover, the search must not include only the mobile app store(s) of the specific operating system(s), but also has to include forums, websites, blogs, newsletters, databases, inventories, repositories and mailing lists in the domain of AT.
2. **Download and install the apps:** The identified mobile AT apps have to be installed on representative mobile devices (both smartphones and tablets) running one of the latest versions of mobile operating systems. The inventory has to include information on the specific models of the mobile devices and the version of the operating system that has been used for installation and testing. Mobile apps that cannot be installed or are failing to run are excluded from the next steps.
3. **Test and evaluate the installed mobile AT apps:** AT experts test and evaluate the mobile AT apps installed, in order to identify whether the application is in line with the scope and functionality its manufacturer claims. Specific criteria must be met by the apps to be included in the inventory. For example, the inventory's developers could decide not to include apps that do not support the English language, or to only include apps that run on Android. These criteria should be made public on the inventory's website.

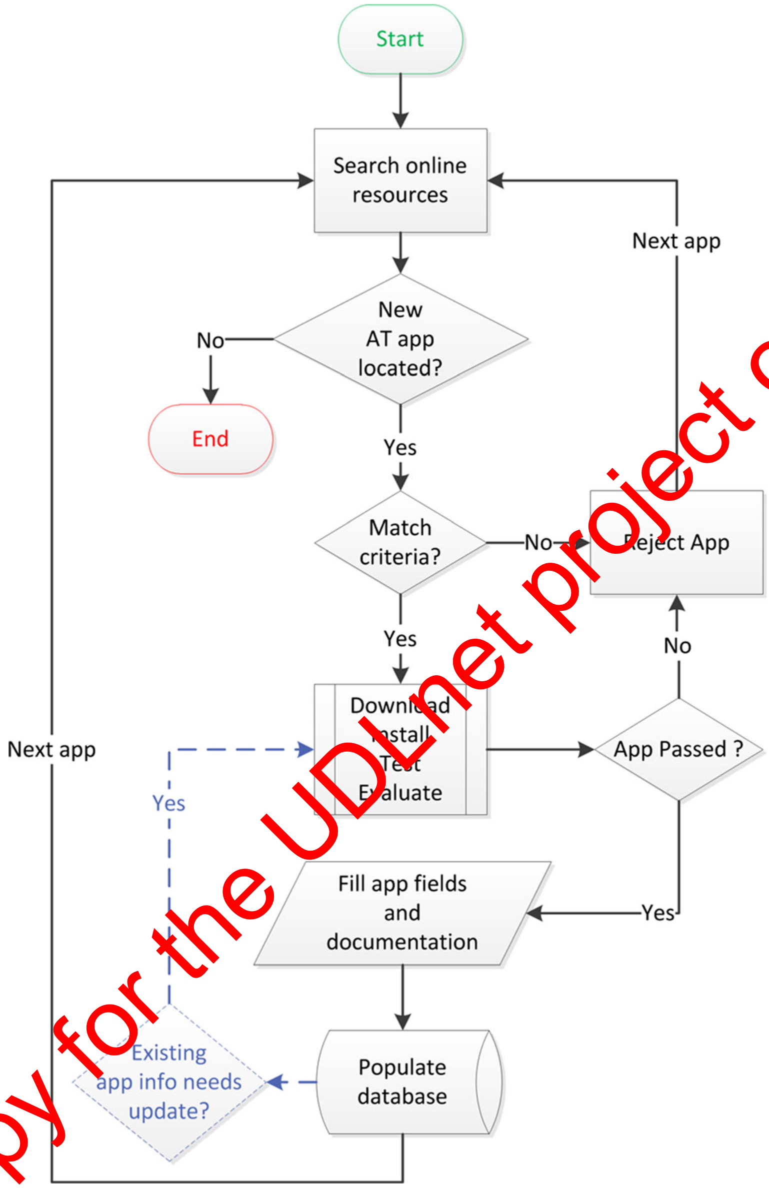

Fig. 1 Flowchart of the AT app selection procedure

4. **Create consistent documentation for each app:** It is important to have a consistent description of each selected mobile AT app. The description must include the same fields for all apps and roughly the same amount of information. Optimally, the experts involved in the previous step must create the documentation. We propose the following fields to be included: the official app name, the name and URL of the manufacturer/developer, the app logo, the URL for download from the app store (iTunes App Store, Google Play), a screenshot (where applicable), the required operating system

and its minimum version, the latest app version, the disability/ies it addresses, a classification according to its application domain or scope, a short description of its functionality, and a long one describing its main characteristics and setting, the languages it supports, and the specific models of mobile devices used during the tests along with their operating system's version.

5. **Design the facilities of the inventory and build it:** It is crucial to select the appropriate search facilities and functionalities of the inventory. We propose the following five search and selection modes: a) search by disability, b) search by operating system (Android, iOS, MS-Windows), c) search by application category, d) search using keywords, and e) search in alphabetical order. A rating system, along with a field for user comments are also suggested. It is preferable to present all the information for a specific app in a single web-page. Moreover, it is essential for the inventory to be accessible according to the Web Content Accessibility Guidelines (WCAG) 2.0 [66] at least for the level AA of conformance [67].
6. **Update and maintain the inventory:** Checking frequently for new mobile AT applications, as well as updating the information of existing apps when new versions are released, constitute an important part of the life cycle of the inventory. This part of the procedure is illustrated in blue dashed lines in Fig. 1. Also, visitors' comments or complaints for bugs, errors, or improvements should be welcomed and considered very carefully.

5 Results

Following the aforementioned methodology we have designed and developed *mATHENA: a free AT software inventory for mobile devices* (smartphones and tablets) [40, 57]. mATHENA is based on its predecessor, the *ATHENA: free AT software inventory* [49, 56], which was developed in 2009 and comprised applications only for Windows-based PCs (desktops, laptops, etc.).

5.1 Application of the methodology: the mATHENA inventory

We searched various online resources in order to locate the AT apps that matched our criteria: 1) apps should be available for downloading and their installation should succeed without problems; 2) installed apps were first checked in order to verify that they really are apps that belong to the Assistive Technology category and do what their developer claims they do; 3) English language should be supported by the app. The testing procedure followed including functionality and settings testing, and usability evaluation (more details and results are given in the following Section 5.2). The specialized scientific personnel that conducted the test and evaluation, also wrote all documentation for each app, and registered all fields and data in the inventory's database; the web-based user interface of the inventory was created focusing on accessibility and usability; all search capabilities were designed and implemented according to the suggested methodology. Finally, the proposed features of the website were developed (file transferring system, commenting system, rating system). The mATHENA inventory is updated twice a month (for example if a new version of an app is available).

We decided to include only free of charge apps in mATHENA. Free apps, are applications developed by an organization, a company, or freelance developers and are available without cost to users [15, 47, 48, 51]. Many times, the purpose of a free app is the demonstration of the company's quality of app design, in order for the user to buy a commercial application from the same company in the future. In other cases, organizations and freelancer developers who develop such applications don't have any direct financial profit, but just want to offer their services to the society in this way. Some free app developers earn money from the advertisements in the pop-up windows, which appear in frequent periods of time while the application is running. A free app lite edition is an application with fewer features than its commercial version. The user comes in contact with the interface and the basic functions of the app, and has to pay for the extra features if he wants to use them. Finally, a free app trial edition is the original commercial edition of the application, but with limitations in the usage period.

5.2 Test of the mATHENA inventory

We explored and examined more than 200 different forums, websites, discussion lists, blogs, newsletters, and application stores (iTunes app store, Google play), including the inventories mentioned above. We collected a total of 1100 apps (Table 3). Among them, 380 did not offer a free of charge version. Thirty apps failed to download. Moreover, 5 apps failed to run smoothly (either because of software crashes or because of failing to open their interface on the device display). 190 apps, although they are referred as AT apps, were excluded after the evaluation, as they were classified as non-AT apps. 75 applications that did not have their menu in English were also rejected. Finally, 420 mobile AT applications for iOS and Android devices were selected to be included in the mATHENA inventory.

All the applications included in mATHENA have been tested by AT experts of the Speech and Accessibility Lab, University of Athens. Moreover, the same experts were the authors of the documentation for each AT app in mATHENA. Figure 2 presents the 36 available AT categories in mATHENA. In order to increase the usability of this webpage, each category is represented with a unique icon. Clicking on the name of a category or its icon leads to a list of apps pertaining to that category. Table 4 presents the main fields of mATHENA, i.e., the included details (fields) for each mobile AT application, as well as the inventory features, compared with the relative information for the six inventories presented in Section 3.

Table 3 Mobile AT applications located, tested, and selected by applying the proposed methodology in order to populate the mATHENA inventory

	Number	%
Total mobile AT apps located	1100	100.0
Applications not free of charge	380	34.5
Applications failed to download or run	45	3.2
Non-AT apps	190	17.3
Applications not supporting the English language	75	6.8
Applications finally selected for mATHENA	420	38.2

Fig. 2 Screenshot of the AT categories in mATHENA

Table 5 presents the results of the accessibility assessment for the seven inventories. For each one, we have selected three indicative webpages (the homepage, a page with a list of apps and a search page). For the overall assessment, we used the tools WAVE [64] and A-Checker [8] (A and AA levels of conformance for both). For the XHTML markup check, the W3C Markup Validation Service [62], and for validating the Cascading Style Sheets (CSS), the W3C CSS Validation Service [63], was used. We found that mATHENA is the only inventory without errors for all the tools used.

6 Conclusions

In this work, first we presented the main characteristics of the AT user groups and the correlation of their needs with the required mobile software adaptations. Then, we introduced a novel methodological approach for the design and development of web-based inventories for mobile AT apps. This methodology aims on the consistent and well-documented presentation

Table 4 Overview of the information fields given for each product, and the most important website features for a: SpecialNeedApps [16], b: BridgingApps [14], c: AppleVis [4], d: AppsforAAC [5], e: AssistIreland [17], f: LowVisionBureau [43], g: mATHENA [57]

a	b	c	d	e	f	g	
Details for each app							
•	•	•	•	•	•	•	Application Name
•	•	•	•	•	•	•	Description
•	•	•	•			•	Manufacturer
•	•			•	•	•	Application Logo
		•				•	Version
•	•					•	Screenshots
						•	System Requirements for App
•	•	•			•	•	Download URL
	•	•				•	Developer URL
	•					•	Languages
Inventory features							
•	•	•			•	•	Search field
•	•	•	•	•	•	•	Filter *Categories*
				•		•	Filter *Disability*
						•	Only Free of charge Apps
		•					Add Comment
•	•					•	Rating System
•	•	•	•			•	Alphabetical List of all Apps
•	•		•			•	Filter *Operating System*

of the information for each mobile AT app, after it is tested in an AT lab. The mATHENA inventory of free AT apps for mobile devices (smartphones and tablets) has been created by following the above methodology. The advantage of mATHENA compared with the functionalities of six other relative inventories for AT applications has been also shown. Currently, mATHENA includes 420 free mobile AT applications, thoroughly selected after testing among a total of 1100.

We plan to extend mATHENA by adding more languages, such as German and Spanish. Moreover, we plan to include AT apps related to new innovations in mobile technologies, both in hardware (e.g., smartwatch) and software that can potentially benefit the disabled and elderly.

Table 5 Accessibility results (total number of errors) for the websites of the inventories a: SpecialNeedApps [16], b: BridgingApps [14], c: AppleVis [4], d: AppsforAAC [5], e: AssistIreland [17], f: LowVisionBureau [43], g: mATHENA [57]

	a	b	c	d	e	f	g
WAVE [64]	3	31	0	1	5	20	0
A-checker [8] *level A*	6	26	7	1	5	12	0
A-checker [8] *level AA*	0	23	0	0	487	4	0
Markup validator [62]	0	158	102	99	24	89	0
CSS validator [63]	45	51	4	15	2	11	0

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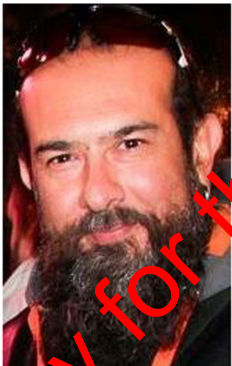

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