A Smart Supermarket must be for All: a Case Study Including the Visually Impaired

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ABSTRACT
Shopping in the supermarket is a necessity in modern life. This task, however, can be a challenge for people with disabilities, making them dependent on relatives or supermarket employees to aid them. In this paper, we investigate the subject by proposing and experimenting a system that takes advantage of current ubiquitous computing to support all customers in finding and selecting products in a supermarket. Based on the Internet of Things (IoT), this system is embedded in a mobile platform. A case study conducted with users – including visually impaired ones – is reported and discussed. The results are compared with previous experiments conducted with users without disabilities, revealing the impact the system has in terms of efficiency, and feelings of satisfaction, control and motivation.

Author Keywords
Human-Computer Interaction; Ubiquitous Computing; Internet of Things; IoT; Web of Things; WoT; Natural User Interfaces; Mobile.

ACM Classification Keywords
H.5.2 [**Human-Computer Interaction**]: User Interfaces – *Evaluation/methodology, User-centered design.*

INTRODUCTION
In the year 2000, Hall [3] envisioned a smart city as a safe, efficient and environmentally green urban center, made possible by the use of integrated materials, sensors, electronics and networks. The main idea is that such city can optimize its resources, monitor security aspects and provide better services to its citizens. More than ten years later, Nam & Pardo [14] collected all the synonyms for "smart city" used in literature and characterized the term as the intersection of three dimensions: technological, institutional and human. The first refers to the computing infrastructure that is necessary to transform life and work in a city. Institutional refers to policy and regulations necessary to make it all possible. Lastly, human factors is about the intellectual and social capital indispensable to build a smart city. It refers also to social inclusion and accessibility smart cities might bring.

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In sight of the presented concepts, in this paper, we focus on both the technology and the human aspects of smart cities. More specifically, we chose a particular scenario – a supermarket – to explore how smart technologies can help any person (in particular, those with visual disabilities) to find and select products. We also empower people to help each other by leaving comments about products in the supermarket, as if in e-commerce stores, but in this case, the comments are associated to the physical objects of the store.

Regarding technology, we share the vision of Lea & Blackstock [7] that the Internet of Things (IoT) paradigm can be a platform for smart cities. IoT may be defined as the enhancement of everyday objects by electronic devices, making them intelligent and connected to the Internet [4]. Moreover, IoT refers to this network of smart objects, the technology necessary to support it, and the set of applications and services that drive them to create business opportunities [13]. An easy and low-cost way to make an object smart is by using RFID (Radio Frequency Identification) technology. This is a common alternative to barcodes for identifying objects [4], since there is no need for a careful positioning between the barcode and its reader. The electronic tags, called RFID tags, store the unique identifier of an object, and an RFID reader can scan the tags from a small distance, not requiring much precision. This simplicity supports the tracking of physical objects within well-defined spaces, but it can be a challenge to deploy a network of RIFD tags and readers [5]. However, it is possible to create an IoT with RFID, as Welbourne et al [16] have succeeded in doing so, and in creating web-based tools that allowed users to manage their smart objects.

For the human dimension, we focus on two pillars. The first is Universal Design (UD), i.e. "creating environments and products that are usable by all people to the greatest extent possible." [9]. Hence, we see the pervasiveness of smart cities as a two-way street: at the same time that it reaches and monitors people, it should be accessed by anyone, regardless of culture, age, gender, disability or any other characteristic. Our second pillar are Natural User Interfaces (NUIs). Popularized by Ballmer in 2010 [1], this term refers to ways of interaction that go beyond the mouse and keyboard, such as gestural, voice-based, touch and tangible, for instance. However, we agree with O'Hara et al [15] that the feelings of "naturalness" provided by a system are more important than the technologies employed. In this sense, the ubiquitous nature of the IoT joined with the easy-of-use of RFID technology, constitute a NUI with a seamless interface.

Bearing in mind the explained aspects of technology and human factors, in this paper we present a system that implements the Internet of Things, using RFID, within the scenario of an inclusive supermarket. It is an embedded solution of the Universal Navigation Exploration and eXchange with Things (U-NEXT) system, which supports people while they explore, for instance, a supermarket and its products. We evaluated the system in two experimental scenarios. The first was with students from a graduate discipline, and the other was with visually impaired users. Our aim was to explore this scenario to understand real technical and usage problems that impact different audiences and also on the system environment as a whole.

The paper is organized as follows: The next section introduces the U-NEXT System architecture and its instantiation. Then, we present our case study followed by discussion of main findings. The paper concludes with considerations and directions for future research.

THE U-NEXT SYSTEM ARCHITECTURE

Universal Navigation, Exploration and eXchange with Things (U-NEXT) is a pervasive system that uses Internet of Things services to promote interaction and exchange of information among people, objects and smart devices. It seeks to promote direct and indirect collaboration between users, devices and environment [12]. As it was conceived, this system architecture is meant to adapt to several contexts and scenarios, but this research focuses on Accessibility and Universal Design issues. As premises, the system seeks to explore the smartness of "things" involved in the IoT to:

- Promote utility services to, directly or indirectly, benefit people with and without disabilities.
- Be portable so that other devices can connect to it to exchange information or services.
- Allow any user to help other users, with or without disabilities, serving a wide variety of needs.

In its initial idea, the U-NEXT System was designed with a laptop-based core connected with a USB RFID (Radio Frequency Identification) reader and RFID tags that acted as devices in an Internet of Things scenario [12]. The system core (our authorship) identifies codes (IDs) from RFID tags and identifies text messages associated with those IDs, converting them to a synthesized voice, which in turn the user hears. The system core also works as a gateway component between the world of RFID tags and the Internet.

Initial tests with the U-NEXT system, in its preliminary stage [11,12] have shown that the technology used could be directed to a more autonomous and flexible solution. In this article, we introduce the concept of enhanced mobility for the system user. The idea is to embed the system core in mobile devices with RFID readers. Our main interest is to provide more comfort and quality of use, based on the improvements identified in previous versions of the system.

The embedded solution driven for mobile devices has brought new design challenges, in terms of both the user interaction and the hardware and software limitations. This solution could be used on any type of mobile operating system (e.g., Windows Phone and iOS), but for economic reasons we chose the Android operating system. Because of technical and project constraints, we chose devices that already have the RFID embedded in the system. Figure 1 shows the concept of the mobile system.

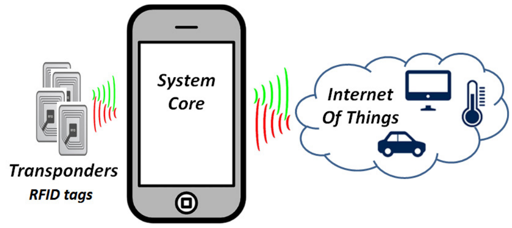

Figure 1. The high-level system architecture.

In the mobile version, the system was developed in Java ME, while in its prototyped laptop version it was developed in Python. The internal architecture of the mobile device must allow the system core to explore operating system resources (e.g., OS events), voice synthesizer system and the interface from the RFID reader. As a design requirement, the system must have a user-friendly interface that considers different users with different skills.

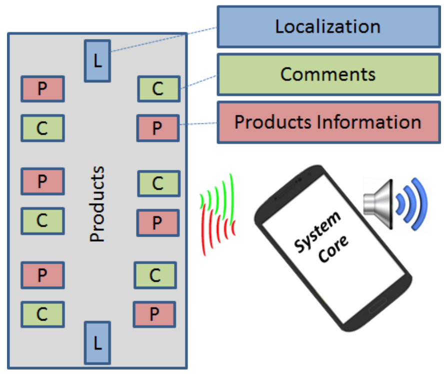

Figure 2. Example of our smart supermarket gondola.

In this study, we instantiate the proposed system architecture (Laptop-Based or Mobile-Based) in a smart supermarket simulated environment. We chose this scenario because it presents many challenges for any user, regardless of having a disability or not. We imagined the scenario as a real supermarket, with gondolas, shelves and corridors. The difference is that in front of each product, on the edge of the shelf, there are two RFID tags: one with basic product information (name, brand, price and weight) and the other with opinions on that product left by other customers. The

RFID tags were covered with paper labels. The label in the product information tag had written in it almost the same information (name, brand and price). The opinions tag had just a visual icon indicating it contained opinions in audio. For the customer navigation, the shelves also had RFID tags indicating the categories of each corridor. These tags were also covered with paper labels that only contained an icon to indicate the audio information. In addition, each corridor had large paper signs naming the kind of product located there. Figure 2 has an example of our smart supermarket gondola.

In this work, we have instantiated this smart supermarket in experimental scenarios, described in the next section.

CASE STUDY

Scenario and Participants

A case study was conducted in a non-profit institution called "Pró-Visão", located in the city of Campinas. The main goal of this organization is the social inclusion of visually impaired people. To achieve this goal, they work with people of all ages, with varying degrees of visual disabilities (i.e. from low vision to complete blindness), and help them to gain autonomy in their day-to-day activities in the society. The institution offers them Braille courses, how to use the white cane, and to develop other skills. It operates as complements from schools to give support for students and their families as well. Several additional activities are offered for the participants such as crafts, sports and recreation, reading, literacy and information technology. A multidisciplinary team of educators, teachers, psychologists and other professional, supports students. Pró-Visão opened its doors to our group and other researchers to the investigation of new techniques e technologies that could be useful to their students in their daily lives, and to its staff. The people (minors and adults) who participated in our studies were indicated by Pró-Visão's staff.

This case study reports and discusses activities organized into two "workshops": the first, a pilot experiment, and the second, a formal experiment.

First Workshop: Pilot Experiment

The objective of this workshop was to allow users with visual impairments to interact with the U-NEXT system (still in the laptop) and explore the supermarket using the system.

We had three participants, all minors accompanied by family members or caretakers. There was one blind teenage boy and two low-vision teenagers, one male and one female. Both had different degrees of low vision. All participants had to accomplish a task: to explore the whole supermarket and choose one item to buy. Hence, the main objective of this workshop was to explore the system for the first time with users with actual visual impairments, serving as a rehearsal for the actual experiment.

Second Workshop: Formal Experiment

The objective of this workshop was to conduct an experiment with users with visual impairments, gathering qualitative and quantitative data from their use of the mobile version of the U-NEXT system.

This workshop had seven participants: two blind adult females, four adults with different degrees of low vision, and a girl with low vision.

Each participant had two goals in this activity. The first was to find and select three items from a shopping list. The second was to leave a comment about one product. They would simply need to speak and the system would use voice recognition to transform their speech into text and store it. Therefore, the main objective of this workshop was to explore the system in a task-oriented manner, so we could compare its usage data with previous experiments.

These workshops followed a specific format and were part of the method we adopted in the study.

Method

As explained in the previous section, the U-NEXT system started as a prototype in a laptop and later became mobile. To support this transition, we organized two workshops: the first represented an exploratory scenario with the laptop prototype, and the second referred to an experiment with the mobile system.

Despite having different objectives (first workshop: exploratory; second workshop: task-oriented), both workshops followed a same format:

1. **Greetings**. Participants and researchers briefly introduce themselves (e.g. they say theirs names or educational backgrounds) when in a first meeting or just greet themselves). It is a moment to break the ice and begin to form bonds of trust. Additionally, it is also an opportunity to know more about their life histories, the abilities and levels of disabilities of each participant, and their ways of doing daily activities, etc.
2. **Signing consent**. This research project has the approval of an ethics committee and, therefore, every participant (or a person legally responsible for the minors) needed to sign a term of consent, saying they are aware of and agree with the research purposes. For people with visual disabilities, we present the option of using a screen reader to listen to the term. For practical reasons, all participants agreed on having a researcher read the term aloud. Besides the signed consent, it is important to note that at all times there was the support from a psychologist or a social worker from Pró-Visão. This person also helped the participants to sign the term, using a ruler and their standard protocol.
3. **Preliminary conversation**. Researchers and participants engage in a small talk to make everyone comfortable with the subject and with each other's presence, asking questions related to the problem at hand, for example, talking about the way participants shop in a supermarket. This is important to gain insights of the real user's perspective on the problem before presenting them with the proposed activities through the system. Results of this conversation also provide essential qualitative data regarding the subject under study.

4. **System Introduction**. Researchers present the system showing the use of the devices that are under test conditions (e.g., RFID reader and transponders). This is important for participants to become familiar with the system and minimize anxiety of participating in the activity.
5. **Experimentation**. The researchers explain the task the participants will perform: shopping in a physical setting that simulates a supermarket. Then, one by one, the participants execute the task, allowing researchers to gather quantitative data, such as execution time, how many times the device was used, how they are used, etc. Some measures are usually logged by the system, other data are registered by the researchers.
6. **Individual Feedback**. After executing the task and interacting with the system, each participant individually responds a questionnaire about their individual experience. For instance, in the second workshop we used an adapted (tangible) form of the Self-Assessment Manikin (SAM) [2], which gave us quantitative parameters for the participants' feelings of valence, arousal and dominance. In the first workshop this phase was suppressed and the individual feedback occurred at the next step (Debriefing).
7. **Debriefing.** After every participant has gone through the previous phases, researchers and participants collectively discuss the experience. Participants, then, provide their qualitative feedback on the system usage by either pointing out the system strengths and weaknesses, or by giving suggestions of improvements or addressing new requirements. Participants also point out other similar systems or experiences they had or would like to have.

RESULTS AND DISCUSSION

In terms of quantitative results, the first workshop provided us only with a baseline for comparison with other experiments, due to it being a pilot. This means we cannot use this data for statistical analysis, but we can make some inferences. In terms of qualitative data, the two workshops were very rich.

The experimental conditions of the second workshop allowed us to compare its quantitative data with an experiment we had conducted previously. In this case, the participants were graduate students from a 1-semester Human Factors course of the State University of Campinas (UNICAMP), in 2014. The original experiment followed the between-group design, meaning we separated the participants in three distinct groups and each group experienced different conditions. Group A represented the traditional way of shopping and had no system to interact with the supermarket. Group B had access to the U-NEXT system to interact with the supermarket, and no restrictions. Finally, Group C also had access to the system, but was blindfolded (simulating blindness). Hence, Group C was a rehearsal for the experiment with visually impaired users.

The null hypothesis of this experiment was the following:

H0: *There is no difference, in terms of execution time and user feelings of valence, arousal and dominance, between using or not using a system connected to the Internet of Things to perform the tasks of finding and selecting products in a supermarket.*

Hence, our alternative hypothesis (**H1**) would be the opposite, i.e. "there *is* difference…".

We were able to reject the null hypothesis in terms of execution time and feelings of motivation, but not in terms of feelings of control and satisfaction [11].

In the second workshop, we are working with the same hypothesis, and the same experimental setup. Therefore, we can treat them as a fourth group in the between group experiment design (which we will call **Group D**), and make statistical analysis with the quantitative data from the four groups.

Hence, in the following subsections we show, discuss and compare both quantitative and qualitative data from the two workshops and from the original experiment. The quantitative data is organized in terms of execution time, feelings of satisfaction, motivation and control, and, finally, in amount of tasks execution.

Execution Time

In both workshops (and in the experiment with the graduate students), we measured how much time each user took to execute their main task. This way, the clock started counting when they entered the supermarket (always through the same place), and stopped when the users signalized they had finished shopping.

Blind Boy	Low-Vision Boy	Low-Vision Girl
493s	231s	320s

Table 1. Execution times (in seconds) in the first workshop.

Table 1 shows the results of the first workshop. The blind boy took the longest time, 8 minutes and 13 seconds (or 493 seconds). The teenage boy with low vision was the fastest, with 3 minutes and 51 seconds (or 231 seconds).

Table 2 shows the results from the experiment with the graduate students (first three columns) and the results from the second workshop (last column). Each line represents a different participant, and the last line, in bold, shows the average time for each group. Since the second workshop had two blind participants, their results have a (B) next to them.

The first aspect that is interesting to note is that the execution time of the first blind from Group D is almost identical to the blind boy's time in Table 1. This could be an indication of the approximate time a blind person would take to explore the simulated supermarket and execute the tasks of finding and selecting products. It is also consistent with the average time of the participants from Group C (blindfolded people).

Another aspect that calls attention is that the second blind person from Group D was the fastest of the group, beating those that have low vision. The reason for this seems to be that the last blind participant was (according to her own testimony) anxious about the experiment, so she sped through the activity to finish it quickly, barely exploring the supermarket. This looked like a positive aspect of the system.

A [no system, no blindfold]		**B** [system, no blindfold]	**C** [blindfold, system]	**D** [system, disabilities]
71,82		207,19	422,85	712
124,78		251,4	421,12	509
147,55		259,14	328,72	492 (**B**)
81,91		208,94	418,66	389
83,77		271,13	782,96	427
107,91		211,15	352,35	458
		238,37		231 (**B**)
Avg	**103**	**235**	**454**	**460**

Table 2. Execution times (in seconds) for Groups A-D.

It is also possible to see that the averages from groups C and D are very close from each other and rather close to the blind boy's time in Table 1. This could indicate that there is no difference, in terms of execution time, between blindfolded and visually impaired users. In turn, this means that, for purposes of experimentation and quantitative analysis, in the early stages of system development there are advantages in simulating a disability.

Finally, we can also see that the average time from Group B (people without disabilities that used the system) is very close to the times of the two low-vision teenagers from the first workshop (Table 1). However, their times are lower than Group D participants who also have low vision. This may be interpreted by the differences in the workshops' tasks. For low vision users, the time to explore the supermarket ranges from 231 to 320 seconds, and the remaining difference of up to 458 seconds is the time it takes them to find the three items of the shopping list, choose from the available options of brand and, finally, comment about any product.

Because this was a between-group experiment with one independent variable and more than two conditions, according to Lazar [6] we can apply the One-Way ANOVA to analyze the data in Table 2 (except for the last line, with the averages). This analysis returned **F=15.6** and **P=0.00001**, which means we can reject the null hypothesis in terms of execution time. Hence, we can conclude that there is a significant difference between using or not using a system connected to the Internet of Things, in the tasks of finding and selecting products in a supermarket.

Satisfaction, Motivation and Control

In the first workshop, there was no time for the participants to complete the SAM questionnaire, so for this subsection we only have the data from the second workshop and the experiment with the graduate students. We asked all groups to evaluate how they felt about the activity. Group A evaluated the experience of shopping in the simulated supermarket without the system, and the other groups evaluated the experience with the system.

Table 3 shows the ratings for the Valence parameter, in which lower values indicate greater feelings of satisfaction and pleasure. The last line, in bold, shows the mode for each column. Just like in the previous subsection, each line represents a different participant.

A [no system, no blindfold]		**B** [system, no blindfold]	**C** [blindfold, system]	**D** [system, disabilities]
3		3	1	1
4		1	3	3
5		1	3	5 (**B**)
7		1	2	1
3		1	6	3
1		4	1	1
		1		3 (**B**)
Mode	**3**	**1**	**1; 3**	**1; 3**

Table 3. Levels of Valence from the SAM questionnaire.

For Group A, it is evident that the grades fluctuate around neutral feelings (between 3 and 7), and that the mode is simply the only value that repeats itself once. Groups C and D also show some fluctuation, but it is closer to their two modes, 1 and 3, showing a tendency towards greater satisfaction. In its turn, Group B has a majority of answers equal to 1, its mode, and highest possible feeling of valence.

Therefore, it is visible that the groups that used the system (B, C, D) tended to feel more satisfaction. However, a statistical analysis with the Kruskal-Wallis method (used with non-parametric data [10]) showed no statistically significant correlation between the groups. Hence, we cannot reject the null hypothesis in terms of feelings of satisfaction.

As for the feelings of Arousal, Table 4 holds the ratings for each group. Again, lower values mean greater feelings of motivation and excitement during the activity. The mode is shown in the last line, in bold. The first interesting aspect to note is that the values from Group A vary a lot, fluctuating between 2 and 6, which indicates neutral feelings of valence. Next, Groups B and C show less variation, with lower values (between 1 and 4), indicating high feelings of excitement. Finally, Group D interestingly shows only two values, 1 and 5, where 5 comes up more. While 1 is the highest value, 5 is the neutral feeling, meaning the visually impaired participants either felt extremely excited, or motivated enough to complete the activity. Moreover, since the last participant from Group D was very anxious and rated her feeling of arousal as neutral, this could be an indication that the others who gave a grade of 5 were also feeling intimidated by the new technology or the activity.

A statistical analysis with the Kruskal-Wallis method gave a correlation between Groups A (traditional way of shopping) and C (blindfolded participants), but with **P=0.17**, which does not surpass the 95% relevance threshold. Therefore, we cannot reject the null hypothesis in terms of motivation.

	A [no system no blindfold]	**B** [system, no blindfold]	**C** [blindfold, system]	**D** [system, disabilities]
	3	3	2	1
	3	2	2	5
	6	1	4	1 (**B**)
	5	3	3	5
	2	1	1	1
	5	2	1	5
		3		5 (**B**)
Mode	**3;5**	**3**	**1; 2**	**5**

Table 4. Levels of Arousal from the SAM questionnaire.

Finally, Table 5 shows the scores for feelings of Dominance and, for this dimension, unlike Tables 3 and 4, higher values indicate greater feelings of control. The last line of the table indicates the mode for each group.

	A [no system, no blindfold]	**B** [system, no blindfold]	**C** [blindfold, system]	**D** [system, disabilities]
	3	6	7	9
	7	9	5	9
	7	5	4	7 (**B**)
	6	8	5	9
	7	8	5	9
	9	5	2	9
		5		9 (**B**)
Mode	**7**	**5**	**5**	**9**

Table 5. Levels of Dominance from the SAM questionnaire.

In Table 5 we can see that Group A shows feelings of dominance fluctuating mostly around its mode, 7. Group B has a wider range of scores, from 5 to 9, with a mode that means neutral feelings of control. Group C has the same mode, but its values are mostly equal to or lower than 5. Finally, Group D has an almost unanimous scoring of 9, the highest feeling of dominance. Hence, we can infer that the group with real disabilities (D) felt much more in control than the blindfolded group (C). In fact, the visually impaired participants (Group D) showed greater feelings of dominance than all the other groups, including those with no disabilities that shopped normally (Group A). This could be an indication that the system gave, especially to the participants with disabilities, a feeling of empowerment.

A statistical analysis with the Kruskal-Wallis method showed a correspondence between Groups B and C, and between Groups C and D, with **P=0.02**. Hence, we can say that, in terms of control, there is a significant difference between using the U-NEXT system when you have a real disability from when you have a simulated one. This makes sense, because a blindfolded person is out of their comfort zone, while a person with an actual visual impairment has had time to get used to the visual limitations. We can also say that there is no statistically significant difference between shopping normally (Group A) and shopping with the system (Groups B, C and D). Therefore, we cannot reject the null hypothesis in terms of feelings of control.

Amount of Tasks Execution

Through the system log we can count how many times each user executed certain tasks. As we did in the experiment with the graduate students, we reasoned that the most prominent tasks in the activity were the following three: listen to product information, listen to comments about a product and listen to navigation information.

Task	**Blind Boy**	**Low-vision Boy**	**Low-vision Girl**
Product Info	12	9	9
Comments	12	8	9
Navigation	4	0	0

Table 6. Amount of times users executed the main tasks in the first workshop.

Table 6 shows the amount of times the participants from the first workshop executed these tasks. The first interesting aspect is that both low-vision teenagers did not use any of the 6 navigation tags, while the blind boy used 4 of them. Another notable fact is that the three participants listened to all of the 9 product information tags, and the blind boy scanned some of them more than once. Practically the same happened with the 9 tags with comments about the products. Therefore, there is an indication that, for users with low-vision, the tags with product information and comments are the most important ones, while for blind users the navigation tags are equally relevant. This could be because low-vision users can somehow navigate on their own, but blind people need as much help as they can get from the environment.

Table 7, Table 8 and Table 9 show the results from the second workshop (Group D) and from the experiment with the graduate students (Groups B and C), regarding the participants' access of functionalities. Each line represents a different participant, and the results from the blind participants in Group D have a (B) next to them. In addition, the last line of these tables, marked in bold, represents the average calculated for each group.

First, Table 7 has the amount of times each participant heard the product information tags. It is evident that participants who could see did not use the product information tag very often, probably because they could see such information in written form. However, Group C on average did not scan all the product information tags, while most of Group D scanned some tags more than once. This happened even though Group D has more low-vision participants than blind ones, opposing our initial observation from the first workshop. This also indicates that, for this task, there is a significant difference between the fake and the real visual disability.

B [system, no blindfold]		**C** [system, blindfold]	**D** [system, disabilities]
0		6	13
4		6	18
2		5	15 (**B**)
2		7	12
3		8	7
0		7	10
0			7 (**B**)
Avg	**2**	**7**	**12**

Table 7. Amount of times users accessed product information.

Since this is a between-group experiment, with one independent variable (U-NEXT system) and three conditions, the appropriate method for statistical analysis is the One-Way ANOVA [6]. Applying this method on Table 7 (without the last line) returned **P=7.9^{-06}** and **F=3.6**. Hence, since P<0.05, we can say there is a significant difference between Groups B, C and D regarding their use of the product information tags. Therefore, the difference is significant not only between fake and real disability, but also between presence and absence of users' visual impairments.

Moving on to the analysis of the task of listening to comments about products, Table 8 shows some changes from Table 7. First, Group B displays an increase in usage of the system. This is justifiable because, unlike the product information, the comments are not available in written format, only in audio.

Second, the average in Group C increases slightly, while in Group D it decreases. However, Table 8 also shows that most of the participants from Group D used all of the comment tags, while in Group C all but one participant accessed less than 9 tags. This could be an indication of how the users with real disabilities were more comfortable with spatial navigation than the simulated blind. Hence, they were able to follow the tags with more consistency, while the users from Group C skipped a few tags.

Another interesting fact to observe in Table 8 is that participants from Group B listened to at most 6 comment tags, 3 below the maximum 9. This indicates they used the information in these tags in a more objective manner, mostly to help them in selecting the three items from the shopping list. Hence, they did not listen to comments about products that were not on the list.

B [system, no blindfold]		**C** [system, blindfold]	**D** [system, disabilities]
4		11	8
6		8	9
5		8	10 (**B**)
5		7	9
4		8	9
4		4	9
4			3 (**B**)
Avg	**5**	**8**	**8**

Table 8. Amount of times users accessed comments about products.

In addition, if we compare Table 6 with Table 8, we can see that the three teenagers from the first workshop used the comment tags similarly to the six adults and one teenager from the second workshop. Again, we remind that the last user from Group D was very anxious, so she tried to finish it very quickly, although not scanning many tags. Finally, applying the one-way ANOVA in Table 8 we get **P=0.005** and **F=3.6**. This means there is a statistically significant difference between the three groups, in terms of listening to comments about products.

B [system, no blindfold]		**C** [system, blindfold]	**D** [system, disabilities]
3		2	2
0		1	0
0		0	3 (**B**)
1		1	0
0		4	0
0		4	0
0			0 (**B**)
Avg	**1**	**2**	**1**

Table 9. Amount of times each user heard the navigation tags.

Regarding the use of the navigation tags, Table 9 shows the results for Groups B, C and D. Consistently with Table 6, most of the low vision users from Group D did not use the navigation tags. Meanwhile, of the two blind participants, the one that was not anxious did use 3 of the 4 tags. There is also a consistency with Group C, where all but one of the participants used at least one navigation tag. In turn, most of Group B (people using U-NEXT system without blindfolds) did not use any navigation tags. This is probably because, in our simulated supermarket, it was possible to see all the aisles, but in a real supermarket, with many gondolas and corridors, even a person with sight would probably need assistance with navigation.

For Table 9, the One-Way ANOVA returned **P=0.14** and F=3.6. Hence, we cannot say there is a significant difference between the three groups related to using the navigation tags.

Our final quantitative analysis is about how many times the participants listened to the shopping list, shown in Table 10. Since in the first workshop there was no shopping list, Group A does not go into this analysis.

B [system, no blindfold]	**C** [system, blindfold]	**D** [system, disabilities]
1	2	1
2	3	1
0	2	1 (**B**)
0	1	2
2	1	1
2	3	1
2		4 (**B**)
Avg **1**	**2**	**2**

Table 10. Amount of times users heard the shopping list.

It is interesting to note in Table 10 that Group B has the smallest average, but most of the participants from this group who used the shopping list tag, did it twice. Considering Group B also had the shopping list in writing, it is a significant number. In contrast, every participant from Groups C and D listened to the shopping list at least once. However, Group D is almost uniform around 1, while Group D varies around 2 or 3 times. This could be an indication of how the memory of those with actual visual impairments is better than the fake blinds' or even than those without visual disabilities. In this case, the one-way ANOVA returns **P=0.45** and **F=3.6**, which means the difference between the three groups, regarding amount of times using the shopping list, is not statistically significant.

Qualitative Feedback

In the two workshops with visually impaired users, we collected qualitative data in the "Conversation" and in the "Debriefing" moments, as explained in the "Case Study" section. In the experiment with the graduate students, we gathered qualitative data through a questionnaire and a debriefing session with all participants after the experiment was done. In the following subsections, we will focus our analysis on the data from the two workshops and use the experiment with the students only as a parameter of comparison, when appropriate.

Shopping Habits

In both workshops, participants reported how hard it is to go shopping on the supermarket. The blind participants said they cannot do it on their own: they need help from either a family member or an employee from the establishment. Those with low vision can go by themselves, but they can have problems with finding the products, if they do not know the supermarket layout. In the case of asking for professional assistance, participants request and have to trust that the employee will seek correct products from the list provided by them. All of them reported on how it is both important and difficult to read information in the packages, such as expiration date, calories or presence of sugar (since some of them are diabetic).

Desires and Expectations

In the first workshop, when asked about how they would like to shop, participants said they had never thought about it before. All they could say was they wished it could be autonomously.

Strategies for Shopping

As strategies for shopping, in the first workshop, participants visited all products around gondolas and then they picked the product of their choice, as this was the scope and instruction for the activity. In the second workshop, even though the objective was different, the participants also tended to explore the supermarket, product-by-product. This possibly was to give them a view of the available options before selecting the products from their shopping list. In this sense, the blind participant who was anxious did not explore it all, she just took the items as soon as she found them.

Main Difficulties

During the experiment, the main difficulty for the participants was to hold the mobile phone in one hand while manipulating other objects (e.g, bag and white cane). In this case, participants were afraid of dropping the phone from their hands. For observers, in a real situation, participants run the risk of forgetting the phone on a shelf. The same type of difficulty was observed in the experience with students, especially Group C.

Pró-Visão participants also had difficulty while they were holding the phone, due to the large size of the phone model chosen by the researchers. This problem can be easily solved by choosing another model or installing the U-NEXT system core in the mobile used currently for consumers.

Finally, most participants (Pró-Visão and students) had difficulty, on the first try, to place the RFID reader in a correct position for the system to read the tag. Participants learned with time that they had to bring the middle of the phone (where the RFID reader is) close to the tags.

System Advantages

The system showed notable advantages over the functionality and time to perform the shopping task. The mobility of the system in a smartphone also allowed participants to have more autonomy during the interaction with the simulated supermarket.

Regarding the functionalities, participants liked having the separation well marked among types of information (price, weight, etc.) for each product present on the shelves. Opinion and comments from other costumers about the products were helpful in the decision making process. For participants, comments are an additional selection criterion that goes beyond the price and product brand. The comments from other consumers instead of comment made by the manufacturer enrich the trust on the feedback about each product, once manufacturers have interests in making sales.

Regarding the time of shopping, participants think it is faster to use the system than to ask for help to any employee at the supermarket. Besides, they are sure they are buying what they want. When someone else helps them shopping, they run the risk of buying a product that they do not want. Therefore, information on the product expiration would be important to be in the system. Navigation information tags (on the shelves) also help participants to save time, because it allows customers to know which products are in the gondola, without having to search product by product.

Different from students' feedbacks, the Pró-Visão participants understood the synthesized voice used by the U-NEXT system; it did not bother them and they thought the speed of speech was adequate for them. However, they think that speed control can be a useful functionality.

System Drawbacks

Almost all participants used the tact to find the information tags on the shelves. Although participants reported being easy to find it, is impossible to know the tag contents before scanning it. Therefore, participants have to listen to each label to identify its contents. However, after they listened to the tag information, they easily distinguished that there are three different kinds of information in several tags around the supermarket (location, comments and product information). Participants also informed that, once they picked up the pattern of information tags coming before comment tags in the shelf, it was easy to identify them beforehand. A possibility for the system is to create tangible information that identifies the different tag types and their contents.

The navigation tags at the end of the gondolas worked well to inform participants about products specificities. For blindfolded participants (group C) and the blind boy, it caused some confusion, regarding the position of the goods and which direction the consumer must take to achieve their ultimate goals. This way, in some cases, one of the participants needed the help of a third party to find gondolas and product position. Giving a more precise information (e.g. use a GPS system) is a likely solution.

Different from felt by the students, the shopping bag did not disturb most participants. Only participants who use the white cane and need to hold the shopping bag were muddled with many artifacts to hold. A possible idea is to place the RFID reader at the end of the white cane and tags on the floor, as proposed by [8]; that solution could facilitate at least navigation minimizing the number of things to hold.

Summary

Overall, the Pró-Visão participants enjoyed the adapted supermarket, and they wish that all supermarkets had similar functionalities, to support them in shopping with more autonomy. After the experience, some improvements were suggested regarding. First, placing additional information in the product (expiration date, calories, lactose presence, trans fat presence, fat percentage, if the product is recommended for diabetics or people with of allergies). Second, improving the localization system, regarding the quality of message information). Third, reducing the device size. Finally, making tactile differentiation (e.g. Braille) for the types of tags (navigation, product information and comments).

CONCLUSION

Shopping in the supermarket is a necessity in modern life that represents a challenge for people with visual disabilities. In this work, we investigate the theme of smart cities, by proposing and studying a smart supermarket scenario. The paper presented a mobile version of the Universal Navigation, Exploration and eXchange with Things (U-NEXT) system. It provides a Natural User Interface that, following Universal Design, aims to help all users with the tasks of finding and selecting products in a supermarket. Then, we presented a case study conducted with visually impaired users. We compared the results of this case study with previous experiments with graduate students without disabilities. Our null hypothesis (H0) was "*There is no difference, in terms of execution time and user feelings of valence, arousal and dominance, between using or not using a system connected to the Internet of Things to perform the tasks of finding and selecting products in a supermarket.*"

In terms of *execution time*, our results showed that there is a significant difference. We found that the graduate students that were blindfolded (Group C) had a similar average time than the users with real disabilities (Group D), but the latter would never be able to shop on their own. In this sense, the system provided them an experience they probably never have had before.

Regarding feelings of *valence*, results showed we cannot reject the null hypothesis. However, most of the ratings indicated high feelings of satisfaction, also observed in the feedback provided during the debriefing sessions.

In terms of feelings of *arousal*, we also cannot reject the null hypothesis. Nevertheless, the ratings from the visually impaired users ranged from neutral to high. The neutral ratings might be a sign of anxiety or intimidation.

Finally, as for the feelings of *dominance*, there is no statistically significant difference between using or not the system. Hence, we cannot reject the null hypothesis. However, this is a good result, because it means the system does not interfere with the users' feelings of control during the shopping activity. Furthermore, the visually impaired users reported higher feelings of dominance than even the users without disabilities.

Therefore, considering that people with visual impairments usually cannot shop on their own, a system that allows them to investigate and explore the environment in a way that augments their senses can be a way to improve their quality of life and autonomy. Hence, by using RFID tags and a system core with a sound output, we have shown that it is possible to provide a low-cost Internet of Things that makes it easier for any user to explore and shop in a supermarket.

As future work, we envision replicating the experiment in a real supermarket, instead of in an experimental setup. This would add more variables, such as flow of people and large background noise. Although the experimental setup also presented environment noise, in a real supermarket it would probably be in a different scale. We will also seek to incorporate in the system the participants' suggestions. Especially, the adding of new information about the products, such as expiration date. In this case, the way we use the RFID tags might have to change, since we have tags in the shelf, not in individual products. In addition, exploring other technologies to implement our solution, such as Arduino, might also be interesting.

A step further in the study would be to explore how to provide more autonomy in real, non-experimental, environments, such as a real supermarket. Doing so in external environments of a smart city, like a busy street, would also present new challenges.

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