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Electronic Travel Aids for Blind Guidance

An Industry Landscape Study

IND ENG 290 Project Report, Fall 2015

Abstract

Electronic travel aids should replace the traditional ones to assist the 253 million vision impaired population globally. It is a striking fact that most of the commercial products nowadays still remain on the similar technology level as about fifty years ago. The emergence of depth sensors and cameras is able to make a change, while the market interest appears to be a challenge.

Date: Dec. 4, 2015

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Section I: Introduction

According to the data published by World Health Organization in 2014, 285 million people (about 4% of the total population) are estimated to be visually impaired worldwide, of whom 39 million are blind and 246 million have low vision. This means that someone in our world goes blind in every five seconds. About 90% of the world's visually impaired live in low-income settings. In developing countries, the public facilities to assist independent travelling of blind people are not as well-established as what are in the U.S., which make their life even harder.

For the US itself, vision impaired population takes about 3% (around 10 million), and 1.3 million are legally blind. Surprisingly, only 109,000 people with vision loss in the U.S. used long canes for navigation and obstacle avoidance purposes. And just over 7000 own guide dogs, which require long-time of training, and have only about six years of service. Therefore, the traditional travel aids are limited in use, invasive, require heavy training or extra care, and most importantly, not social friendly at all.

As the technology develops rapidly nowadays, the industry of small-scale sensors for various applications is emerging. These sensors have enabled some modern functionalities of the smart devices (i.e. tablet, smart phones, iwatch, etc.) and made our lives more colorful. However, we should not neglect the fact that there are a small group of people who urgently need these sensors even to satisfy their basic life needs. By transferring the sensor technology in robotics to human beings, electronic travel aids (ETA) are expected to fulfill two main functions – obstacle detection, as well as environment mapping and navigation. Therefore, the ETAs "translate" the signals received by sensors to other forms of signals recognizable by blind people, such as auditory signals, tactile cues, or stereophonic images.

In this report, I will give a review of the current existing or ever existed ETA products, including their technologies, functions, limitations, and prices. Furthermore, other techniques in state-of-the-art research to solve the problem of blind guidance are also summarized. And finally, the most promising technique will be identified, with its market landscape and future direction discussed.

Section II: Existing or Existed ETA Products

1. Ultrasonic Sensor (Sonar)

Most of the current existing or ever existed ETA products are based on ultrasonic sensors. Working similarly as Radar, ultrasound navigation systems are also called "sonar". They send out acoustic waves in the frequency range beyond human hearing ability (typically from 20 kHz up to several gigaherz), and detect the signals bounced back by the obstacles. In ETA devices, these signals are then translated into either audio or tactile forms to the blind people.

1.1. Type-I

The very first generation of ultrasonic ETA devices are called “Type-I”. They only use single output acoustic waves for object preview, without any extra information from the environment. Thus these types of devices are called “go-no-go” systems, and can only be to provide secondary aid together with white canes or guide dogs. Some major products throughout the years are briefly listed below, and also summarized in Table II-1. Most of them have already exited the market due to product limitations, or most likely commercialization problems.

Started in year 1966, the *Russell Pathsounder* was one of the first commercially produced. It had a vibratory range of 1.83 meters and auditory beeping of 0.81 meters. It can be mounted at chest level, neck level, or on wheelchairs. Although no longer available, Pathsounder paved the way for future developments of ETAs.

In 1972, the *Ultrasonic Cone* invented by Geoff Mowat expanded the range to 4.02 meters, and also provided a switch to shorter distance range of about 1 meter. The divergence cone generated by the acoustic waves could actually cover the size of a human body, providing knee to overhead protection. However, there are certain problems with the device, which may have false readings under cold, rain, heavy snow weather conditions. The Ultrasonic Cone product is also no longer available now.

The Nurion Industries brought out *Polaron* in 1980s. It can either be handheld or chest mounted. This devices offers a range selection of 1.22, 2.44, and 4.88 meters (4, 8, 16 feet), and an option of receiving either vibrotacile or audible signals. However, this device might have had problems for mirror-like surfaces at close distance, and thus probably resdesigned in 2004. The price it used to sell was $892, which seems not available for purchasing anymore.

Another one is called *Sensory 6*, which is a head-mounted or spectacle-mounted device with headphones providing sound information. The range of detection is about 2-3.5 meters, and closer object gives higher pitch in the headphones. It did address the importance of head position, in order to avoid faulty reports. This product was last produced in 1994.

WalkMate was developed in 1993. Similarly with Polaron, it’s either waist-mounted and handheld, with both audio and vibration options available. Instead of a cone-shaped wave range, it projects a U shaped beam of 1.82-meter tall by 0.7-meter wide. The detection range was claimed to be 1.83 meters. This product was recommended for outdoors, however, the beam seemed to have varying issues. It is not available in the market nowadays.

Miniguide US is the only Type-I products still for sale these days. This producted started as least from 2004. Providing a range of 7.92 meters, the price is $545 online. As shown in Figure II-1, it is a mini-sized handle as a secondary aid providing “go-no-go” information.

(Reference: Vance Landford, “Electronic travel aids ETAs, past and present,” slides, TAER April 2004.)

Table II-1: Existing or existed Type-I products

Device / Company	Time	Forward range (meters)	Price (if available)	Problems (if information available)
Pathsounder / Russel	1996 - NA	1.83	-	-
Ultrasonic Cone / Mowat	1972 - NA	4.02	-	Bad weather failure
Polaron / Nurion	1980 – NA	4.88	$892	-

Indurstries				
Sensory 6	NA - 1994	2-3.5	-	Head position important
WalkMate	1993-NA	1.83	-	Beam may vary
Miniguide US	2004-Now	7.92	$545	Miniguide US
Sources:				
1 -Vance Landford, "Electronic travel aids ETAs, past and present," slides, TAER April 2004. 2 –The corresponding company websites for each product.				

1.2. Type-II

Improved on top of Type-I devices, the Type-II generation of ultrasonic ETA systems provide multiple outputs for object preview. While providing information from multiple detection directions simultaneous (e.x. forward, over the head, curb drop-offs), they still remain as "go-no-go" systems. Some major products throughout the years are briefly listed below, and also summarized in Table II-2. Due to the miniaturization of ultrasonic sensors, most of these products were able to integrate with primary tools such as white canes to provide secondary assistance.

The *Wheelchair Pathfinder* is a partner product of Polaron, both from Nurion Indurstries. It works with wheelchair or scooter, and provides multiple outputs for forward, side, and drop-off detections. The range covers 2.44 meters in the forward direction, 1.22 meters above head, 0.3 meters side to side, and 2.44 meters for drop-offs. The price is in the expensive range of $4500. It is not clear that whether this product is still purchasable nowadays.

Laser Cane had a long history of development and multiple generations of products, with the latest one named "N-2000". While using laser beams instead of acoustic waves to detect distance, the working principle is still "sonar". This newest version of product provides 3 beams to straight, over-head, and for downward for drops. Because the sensor is integrated inside the cane, single hand operation all at once is possible by operating stimulators under index finger. When the power is off, it can still be used as a regular cane. Laser Cane N-2000 was studied the most by the government, and is still available for $2650 today. The laser technology probably makes it more expensive than a ultrasonic sensor based cane.

The *Guide Cane* project proposed a cane working like a "robotic dog". The ultrasonic sensors detect objects up to 3.5-meter away and send back signals to the computer, which determines suitable direction and steers the guide cane and use around it. This type of cane guides without any conscious effort from the user. However, the promising projected ended in 1998 and was never commercialized.

After a debate of using cane or torch to carry ultrasonic sensors, Dr. Leslie Kay developed a combination – *BAT 'K' Sonar Torch-Cane*. The website of the company Bay Advanced Technologies Ltd introduced this product without further update since 2003, neither a product for purchase is available.

Another example of sonar torch was the *Trisensor* , which was well used in Japan in 1978, and manufactured into 1990s. Its demise was purely due to commercial matters including cost, training, and agency support. The miniaturized low-cost Sonar Torch was later adopted for the BAT 'K' Sonar Torch-Cane mentioned above.

The only commercially available ultrasonic guide cane online, to my best knowledge, is Ultra Cane. It had a forward detecting range of 2-meter or 4-meter, and 1.6 meters above the head. The price is $635 online.

(Reference: Vance Landford, "Electronic travel aids ETAs, past and present," slides, TAER April 2004.)

Table II-2: Existing or existed Type-II products

Device / Company	Time	Forward range (meters)	Price (if available)	Primary tool
Wheelchair pathfinder / Nurion Industries	NA – seems not available now	2.44 forward, 1.22 above head, 0.3 side-side, 2.44 drop-offs	$4500	Wheelchair
Laser Cane N-2000	NA – still available	3.66 forward	$2650	Cane
Guide Cane	NA – 1998	3.5 forward	-	Cane, wheels
BAT 'K' Cane Handle	NA – 2003 (?)	-	-	Cane with handle
Ultra Cane	NA – still available	2 or 4 forward, 1.6 above head	$635	Cane
Sources:				
1 -Vance Landford, "Electronic travel aids ETAs, past and present," slides, TAER April 2004. 2 –The corresponding company websites for each product.				

1.3. Type-III

The Type-III ultrasonic ETA system was proposed by Dr. Leslie Kay, who was a pioneer in this field and led the developments of Type-I Ultra Sonic Torch (first ETA product in 1965) and Type-II BAT 'K' Cane Handle. In his opinion, the ETAs not only should provide a single object preview, but also need to extract extra information from the surrounding environment. In other words, it ought to be able to give texts rather than only headlines. And the interpretation of tonal characteristics makes the primitive object identification possible. Although only remained as a concept, Type-III drew a great visionary picture for future ETAs, and respect should be given to Dr. Kay.

1.4. Type-IV

The Type-IV ultrasonic ETA device developed on the foundation of Type-III concept. The Sonic Pathfinder was a fruit of advanced computer algorithms, which translates sonic energy of the surroundings to directional music notes. While providing a picture-like effect, it only displays information of practical interest to users instead of being too sensitive and overwhelming. However, this was still identified as a secondary aid, and only remained as a research project in 1996.

(Reference: Vance Landford, "Electronic travel aids ETAs, past and present," slides, TAER April 2004.)

1.5. Limitations of ultrasonic sensors

From the above study, the only available products based on ultrasonic devices seem to be Mini-guide US ($545), UltraCane ($635), and Laser Cane ($2650, not acoustic waves but still "sonar" like), displayed in Figure A-1. Unfortunately, they still remain as secondary aids and give only "go-no-go" information. Except for that, the nature of acoustic waves decides that no precise information about shape and motion status of obstacles can be given. The range and resolution ultrasound can detect are limited, while the response is also too slow for fast walking. Most importantly, the acoustic waves interfere with the normal sounds and create screening effects, which influences the normal hearing of blind people and greatly impairs their self-confidence.

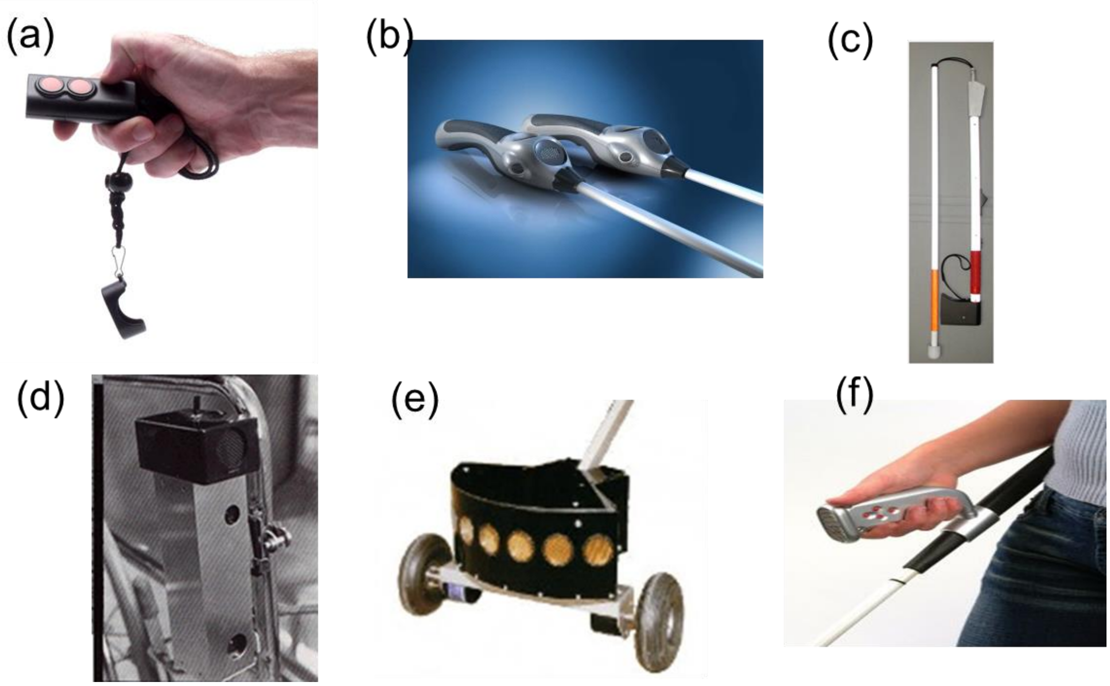

Figure II-1: Current commercially available ultrasonic ETA devices: (a) Type-I Miniguide US; (b) Type-II UltraCane; (c) Type-II Laser Cane N-2000. Other Type-II devices: (d) Wheelchair pathfinder from Nurion Industries; (e) Guide Cane; (f) BAT 'K' Cane Handle from Bay Advanced Technologies Ltd. (Sources of images: 1 -Vance Landford, "Electronic travel aids ETAs, past and present," slides, TAER April 2004. 2 –The corresponding company websites for each product).

Section III: State-of-the-art Technologies

Motivated by the drawbacks of existing ultrasonic sensor based ETA systems, researchers have devoted to studying other approaches including infrared sensors, various cameras, and a combination of both.

1. Infrared Sensor

The infrared sensor enables the ETA devices to provide material recognition and shape analysis of the target object, benefiting the nature of light – directional and focused. The working mechanism used in the referenced paper is also different from "sonar", using the triangulation of light beams to calculate distance. The range of detection is 10 centimeters to 1.5 meters with 93% reported. And the response time is 39 milliseconds, a lot faster compared with 100-200 milliseconds for ultrasonic sensors.
(Reference: A.S. Al-Fahoum, et al, "A smart microcontroller-based blind guidance," Hindawi, 2013)

2. Cameras

2.1. 2D Cameras and the vOICe

The ideal effect for ETA systems is to create a whole picture instead of just pointwise information for users. The challenge is how to translate visual picture into a form that is acceptable for vision impaired people. Advanced neuroscience studies have shown that the visual cortex of even adult blind people can become responsive to sound, and sound-induced illusory flashes can be evoked in most sighted people as well. The vOICe vision technology for the totally blind offers the experience of live camera views through sophisticated image-to-rendering processes. It then creates an acoustic panorama (sweeping sound from one ear to another) through stereophonic effect. In theory this use of digital senses could lead to synthetic vision with truly visual sensations through crossmodal sensory integration, by exploiting the neural plasticity of the human brain through training and education. The ultimate goal is to blind visual input to visual sensations with a minimum of training time and effort, and to improve the quality of life for blind users. It also provides a research platform for the cognitive sciences to learn more about the dynamics of large-scale adaptive processes. The vOICe technology may now build on this with live video from an unobstrusive head-mounted camera (either CCD or CMOS based). The drawback for a 2D camera, obviously, is the lack of 3D ranging ability. While still on the research stage, vOICe software may be able to combine with any 3D camera or depth sensor in the future.
(Reference: vOICe website https://www.seeingwithsound.com/)

2.2. Stereo Camera

In order to give normal 2D cameras a hint of 3D effect, the stereo camera was invented. Stereo camera is a type of camera with two or more lenses with a separate image sensor or film frame for each lens. This allows the camera to simulate human binocular vision, and therefore gives it the ability to capture 3D images, a process known as stereo photography. Stereo cameras may be used for making stereoviews and 3D pictures for movies, or for ranging imaging. 3D pictures can also be taken inexpensively with one camera two positions. If the image is edited so that each eye sees a different image, then the image will appear to be 3D. While trying to mimic human eyes, they still cannot work as well as our eyes. Especially for a low-texured area, the system reported in [ref 1] gives inaccurate depth information. Another version based on RGB-D camera was later introduced [ref 2], with improvements in both object disparity map and traversability map for path generation.

(Reference 1: V. Pradeep, et al, "Robot vision for the visually impaired," IEEE confer. 2010;
Reference 2: Y. H. Lee, et al, "RGB-D camera based navigation for the visually impaired," IEEE confer. 2011)

3. Projected-light 3D Camera

Combing stereo camera or RGB camera with the projection of structured/patterned light (usually infrared), the projected-light 3D camera was a great invention. In addition to a 2D image, depth information on each pixel can be drawn by analyzing the distortion of the mesh pattern through triangulation. The most famous 3D camera based on this is Microsoft Kinect. The depth sensor consists of an infrared laser projector combined with a monochrome CMOS sensor, which captures vedio data in 3D under any ambient light conditions. The sensing range of the depth sensor is adjustable, and Kinect software is capable of automatically calibrating the sensor. Similar products include Ensenso N10, Asus Xtion, and Apple PrimeSense Carmine. However, most of these products are designed for indoor gaming applications. Thus the range is not that great – with Kinect providing 0.7-3.5 meters and Carmine giving 0.35-1.4 meters, and resolution gets worse with farther distance. Furthermore, the light source used does not work very well under outdoor lighting conditions.

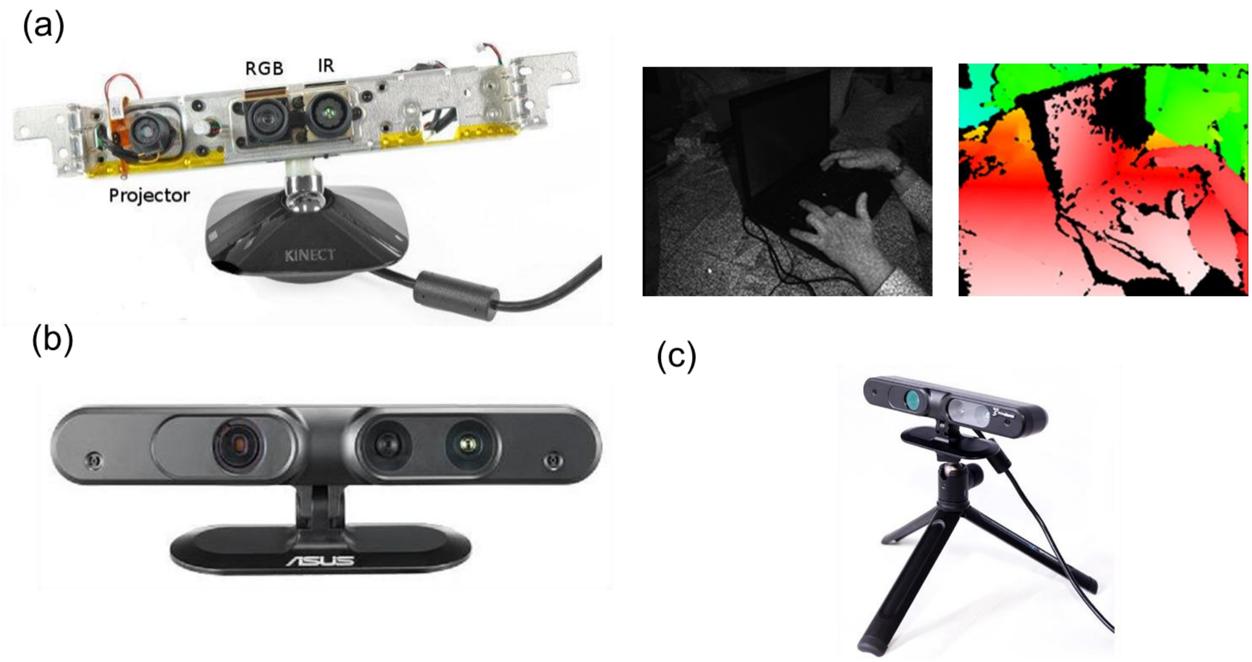

Figure III-1: Projected-light 3D cameras: (a) Microsoft Kinect - the infrared image (left) shows the laser grid Kinect uses to calculate depth, and the depth map (right) is visualized using color gradients from white (near) to blue (far); (b) Asus Xtion; (c) Apple PrimeSense Carmine. (Sources of images: 1 – K.Litomisky, UC Davis, thesis, 2012. 2- Wikipedia and corresponding company websites for each product.)

Section IV: The Emerging 3D LiDAR Market and Projection

Depth cameras go by many names: ranging camera, flash LiDAR, time-of-flight (ToF) camera, and RGB-D camera. The underlying sensing mechanisms are equally varied: range-gated ToF, RF-modulated ToF, pulsed-light ToF, and projected-light stereo (introduced above). LiDAR (also written LADAR) is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. Although thought by some to be an acronym of Light Detection And Ranging, the term LiDAR was actually created as a portmanteau of “light” and “radar”. The working principle is similar with radar, except the “time-of-flight” (ToF) is a lot shorter, putting a much higher requirement on the detector side, requiring a resolution of nanoseconds.

1. Current 3D LiDAR Products

There are generally two ways of realizing a 3D LiDAR camera. The flash LiDAR takes the whole image in one single shot by expanding and projecting light beam from laser source through lenses. The other way is to scan the laser source mechanically, thus it is also referred as “laser scanner”. The method to detect ToF also could be either by pulsed light ToF, or modulated light.

The state-of-the-art 3D LiDAR cameras are summarized in Table IV-1 and Figure IV-1. The range varies from several meters up to a kilometer, with great resolution and broad viewing angle. However, all of them target at high-end markets, thus the price is way too high for it to be used in ETA systems. The cheaper LiDARs existing are usually pointwise devices (similar with Type-I sonars), not capable of “flash” or “scanning”. For instance, PulsedLight offers LiDAR-Lite 2 (40 meters in range, and 1 centimeter of resolution) at a price of $115. As mentioned above, the requirement for timing resolution of detectors is very demanding. And to create a 2D image, an array of expensive detectors are usually needed. This leads to the high price of current 3D LiDAR cameras, in addition to the expensive synchronization electronics. The targeted application here for ETAs really only needs a “compromised” version of 3D LiDAR camera, with a range of 10-meter perhaps, resolution of 1-by-1-ppi good enough, and field of view of 40 °x 40 °at most.

Table IV-1: Representing products in the 3D LiDAR camera market

Product	Company	Approach	Range and Resolution	Field of View	Price
Swiss Ranger 4000	Heptagon	Modulated	5-8m, 176x14 pixel	43.6 °x 34.6 °	$9K
CamCube 2.0	PMD Tech.	-	7m, 204x204 pixel	40 °x 40 °	$12K
Puck	Velodyne	Pulsed, scanner	100m	360 °x 30 °	$8K
TigerCub	ASC3D	Pulsed, flash	~1km	-	$50K
Sources:					
1 -http://www.hizook.com/blog/2010/03/28/low-cost-depth-cameras-aka-ranging-cameras-or-rgb-d-cameras-emerge-2010 2 –The corresponding company websites for each product.					

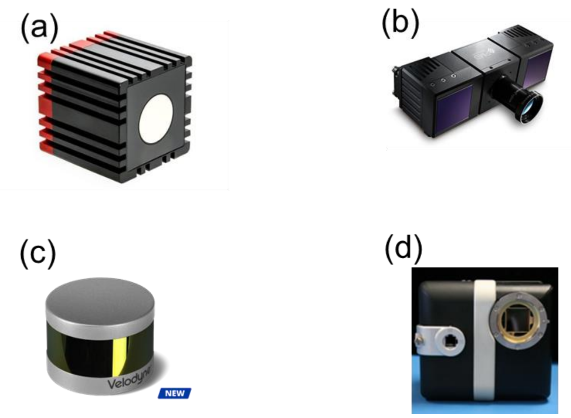

Figure IV-1: Representing 3D LiDAR cameras: (a) Swiss Ranger 4000 modulated-light LiDAR camera from Heptagon Mesa Imaging; (b) CamCube 2.0 from PMD Technologies; (c) Puck pulsed-light scanning 3D LiDAR camera, a new product from Velodyne; (d) TigerCub pulsed-light 3D flash LiDAR camera from Advanced Scientific Concepts. (Sources of images: the corresponding company websites for each product).

2. Projection of the 3D LiDAR Market

Global LiDAR market is expected to reach $624.9 million by year 2020. While the biggest applications are still corridal mapping, seismology, exploration and detection (i.e. space), the emerging markets of autonomous cars and robotics attract much attention recently. The 253 million vision-impaired people certainly will benefit from 3D LiDAR technology (maybe combined with vOICe software) if it is used in ETA systems, but the price they are willing to pay places a show-stopper right now. Before LiDAR technologies get mature enough, and the price is driven lower by flourishing of the big markets, no investor is likely to pay attention to the low-end markets. Therefore, 3D LiDAR –enabled electronic travel aids for blind people, together with other low-end markets, might still remain as white space for a bit longer.
(Reference: https://www.alliedmarketresearch.com/lidar-market)

Bibliography

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