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Concept and Design of SEES (Smart Environment Explorer Stick) for Visually Impaired Person Mobility Assistance

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Abstract **–With the advent of robot companion concept, the independent mobility became one of the hottest problem in general, and allows make progress on the independent mobility of the Visually Impaired Person (VIP). Today, this latter is based mainly on two elements: the white stick and VIPs memory. However, the feedback provided by a white cane, even an enhanced one (a smart stick), is not adequate with the principle of autonomy and with the growing complexity of our cities. Therefore, new capabilities such as orientation and space awareness should be acquired by VIP. The first prototype of SEES (SEE-stick and SEE-phone) is presented in this paper.**

This paper (1) introduces concepts of orientation and space awareness, (2) outlines the architecture of the SEES (Smart Environment Explorer Stick), an enhanced white cane, which assists the VIP's to acquire orientation and space awareness capabilities, and (3) discusses the SEES possible implementation (SEES hardware and software first prototype).

Keywords: **mobility, mobility assistive device for Visually Impaired, orientation, space awareness, multi-sensor, GPS, smart stick, a space explorer smart stick (SESS), SEES (Smart Environment Explorer Stick)**

I. INTRODUCTION

Data from WHO (2011) indicates that there are 285 millions visually impaired people (VIP) currently in the world, 39 millions of them are blind and 246 millions have the low vision [1]. Approximately 90% of people with visual impairment live in developing countries. About 65% of all people who are visually impaired are aged 50 or more, while this age group comprises about 20% of the world's population. Information from EBU (European Blind Union) [2] estimates that more than 30 millions of blind and partially sighted persons live in Europe, and, in the average, 1 of 30 European experiences sight loss, i.e. there are four times more partially sighted than totally blind persons. In Indonesia, 1.5% of Indonesia's population (approximately 3.6 millions) is estimated to be blind what indicates that the blindness is one of the most important epidemiological problems [3]. According to the survey in France [4], prevalence of visual impairment increases exponentially with age as shown in Table 1.

Table 1. Prevalence of visual impairment at older ages in France

Age/ Type of Visual Impairment	60-69	70-79	80-89	90-99	100+
Low vision	3.06	5.92	14.10	23.13	33.71
Total blindness	0.21	0.09	0.91	4.73	3.27
Visual impairment	3.27	6.01	15.01	27.86	36.88

The above statistics show that it is necessary to find the most appropriate solutions for VIP integration in the modern society and to assist their independent life and interaction. Blindness and visual impairments are a major hindrance in daily life such as access information or interaction with the environment.

The *mobility* is a one possible interaction with the external world. The human *autonomous mobility* is a capability to reach a place B from the current place A without assistance of another person. However, the autonomous mobility raises several problems [5-6]; two of them, namely *orientation* and *space awareness*, are keys elements for a true independent mobility.

The concept of (self) *orientation* means the knowledge of the relative spatial position between our current position A and targeted spatial location B. Two basic questions which subtend the orientation are: *"where I am now?"* and *"how to reach the destination from my current position?"*. Consequently, the orientation allows planning globally a specific route (path) to reach the targeted location from the current point.

Space awareness is the capability to know about urban and social data in our peri-personal space ("space around our body") and our navigational space [7]. Some questions which subtend the space awareness might be: *"what are the nearest streets located one with respect to the other and with respect to me? what is the traffic light status at the street I like to cross? where is the library I like to get in? "*. Consequently, the space awareness permits to understand how our nearest space is organized and how we can interact with.

Existing mobility systems to assist the VIP's navigation in the known/unknown and indoor/outdoor environments do not usually support the orientation and space awareness concepts.

This paper proposes to fill this gap by defining a new assistive device for VIP and named SEES 'Environment Explorer Smart Stick'; this device aims to assist some basic sub-functions of the orientation and space awareness.

Therefore, the paper is organized as follows: Section 2 provides a state-of-the-art on the available devices for VIP mobility and focus on technological solution to support *space awareness* concept; Section 3 outlines the SEES architecture; Section 4 propose very preliminary technical evaluation of the SEES prototype some functions. Section 5 indicates some future works toward a full operational SEES prototype.

II. WHITE CANE EVOLUTION : A STATE OF THE ART

The proposed state-of-art is composed of two synergetic parts: a review of some existing cane bases solutions for VIP mobility (2.1) and an introduction of the concept of context-aware human-computer interface (HCI) for VIP mobility (2.2).

2.1. Some existing cane bases solutions for VIP mobility

Several technological solutions have been proposed in order to assist the VIP mobility. This paper investigates only the evolution of assistive devices based on a cane: white cane, smart cane, robotised smart cane and intelligent cane.

The white cane (or white stick) is the first device invented by a British photographer, James Briggs, in 1921 that became blind after an accident, and it still largely used to assist VIP mobility. The white cane assists the VIP's walking by providing the tactile feedback to their hand on the status of their near navigation space; its permits to determine on the ground in a distance around 1m ahead of the VIP, obstacle-free zones and existing obstacles. Once an obstacle detected, the VIP should elaborate an appropriated avoidance procedure by the cognitive integration (synthesis) of the discrete tactile feedbacks. Figure 1 [8] allows to imagine how complex is the global information integration (the whole obstacle shape recognition) using a white stick.

Figure1. Complex procedure of obstacle detection using a white stick

The cane/stick has several drawbacks [9]. Indeed, it does not support the orientation and space awareness: these both functions strongly depend on the VIP memory of his/her surroundings established during the previous mobility experiment (learning) and his/her kinesthesia sense.

The white stick turns into a *smart cane* by adding several sensors to it. These sensors are usually dedicated to detect some obstacles not sensed by the white cane but being located in the reach of the cane (such as overhanging obstacles or upward stairs) or to extend the reach of the cane. These additional obstacles should be localized in the solid angle subtended by (ultrasound or laser) sensors attached to the white cane. A (tactile/hand or audio) feedback to VIP exploits the reflected by the obstacle intensity of the sensor generated energy and captured by the cane. The ”whole” obstacle shape should be ”reconstructed” (cognitively integrated) by the end-user from cane scanned points. The distance to the obstacle is estimated thanks to TOF (Time-of-Fly) between sensor and the reached nearest obstacle. Smart canes provide neither orientation nor space awareness assistance. Several smart canes have been realized; they differ by the feedback sent to the VIP.

The *Teletact* (figure 2) is a handheld laser telemeter device which detects an (overhanging) obstacle with 1% of error at the distance from 10cm to 10m at the rate of 40 measurements per second [10]. The distance is provided through vibrating feedback on the user’s palm hand.

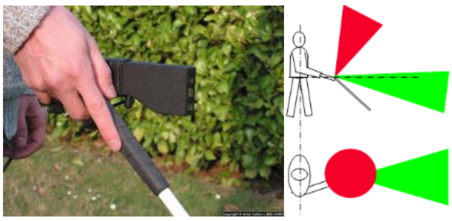

Figure 2. Teletact Cane, University of Paris 11

The *UltraCane* [11], a *smart stick* designed at the University of Leeds (figure 3), uses also the ultrasonic sensor to detect obstacles and transforms this information into vibrations which stimulating a thumb keep on the handle button.

Figure 3. UltraCane, University of Leads

The smart stick *K-Sonar* (figure 4), built at Canterbury University, New Zealand, uses also ultrasonic sensor for obstacle point-wised detection but it provides an audio feedback (space point-wise sonification) [12].

Figure 4. K-Sonar, Canterbury University

The *GuideCane* (figure 5), a smart (robotised) stick, is designed to assist the VIP to detect ground located and specific obstacles such as upward stairs. The set of ultrasonic sensors located on a distal end of the smart stick transform acquired data into a vibrating feedback stimulating the end-user palm [13].

Figure 5. GuideCane, Michigan University

The *SmartCane* of the Indian Institute of Technology (figure 6) [14] detects knee-above obstacles using ultrasons.

Figure 6. SmartCane, Indian Institute of Technology

The *Intelligent Cane* ”iCane” built by the National Taiwan University (figure 7) partly assists the VIP walking (obstacle detection) and basic space awareness. iCane orientation assistance is supported by the RFID tags : data are exchanged between the white cane RFID, and RFIDs embedded in the environment [15]. The data are transmitted to the end-user via PDA headphones connected with Bluetooth to the iCane. The provided information useful for walking is related to the space urbane organisation (e.g. street intersection, elevator, stairs, nearby shops/market, etc.). The main drawback of this system is that the iCane requires RFID instrumented environment (high implementation and maintenance costs, not sustainable solution).

Fig. 7. iCane, National Taiwan University

It should be observed that all current smart sticks do not assist neither orientation nor space awareness. In order to provide the VIPs with such assistances the smart cane/stick should be transformed into a space explorer smart stick (SESS). The SEES system, presented in the section 3, proposes a solution to overcome these limits.

2.2. Context-aware human-computer interface for VIP mobility

A task executed by an agent (human, biological, virtual, etc.) is performed in a certain context. A *context* is a set of all necessary and useful for the considered task execution information (and only this information). For example, as far as the mobility is considered the current status of the environment (user’s near and navigation spaces) should be taken into account. Indeed, if we want to cross a road, there is necessary to check the status of the traffic light which says what is effectively possible to do; we speak about *space awareness.* For VIPs, the environmental noise (such as the car's noise) constitutes the useful space awareness cue on the status of their near space. If the computer is used as a media for interactions with the external world, the contextual data should be provided by the *Human-Computer-Interaction* (HCI) systems.

Currently, one of the most fundamental tasks when building intelligent HCI systems is multimodal sensing and collecting space awareness data (environmental information) pertinent for a given task [16]. The sensors involved in space awareness data collection can be passive or active. The passive sensors do not disturb the observed environment, contrary to the active sensors. A visible spectrum vision sensor (such as a vision camera) is a typical example of passive sensors; an ultrasonic sensor is an example of active sensors.

Some of existing mobility assistance provides very limited space awareness to VIP. "Navigational beacons" for example [17], provide a repeating, directionally selective voice message during the indoor navigation; however, they are limited to this collaborative environment which became intelligent by embedding specific information system and passive sensors into it.

Providing maximal awareness on the environment, without requiring any modification to the existing infrastructures, will significantly enhance the experience of mobility to the VIP in any kind of environments.

However, all (active and passive) sensors should will be integrated in a wearable device what empowers VIP with new sensory capabilities.

Moreover, the HCI system behavior should be organized as a set of states; a transition from one state to the other will be driven by a data provided by the sensors (after their fusion). A feedback to user (a guidance message) will accompany each state transition.

The SEES system presented in the section 3 proposes an integration of the space awareness concept into a wearable unit using several active and passive sensors.

III. THE SEES SYSTEM

This section provides an overview of the targeted space smart explorer stick (SSES) system named SEES (3.1), details of sensors to be integrated in its first prototype (3.2) and SEES system operational modes useful for VIP independent mobility (3.3).

3.1. SEES overall architecture

The SEES system contains three main components (cf. figure 8):

- a global remote server (iSEE),
- an embedded local server (SEE-phone), and
- a smart stick (SEE-stick).

The iSEE is a global server providing the web services for the VIP such as remote real-time hint and help and remote monitoring (trace the VIP location). The SEE-phone is based on a commercial smart phone. It is used as an embedded local server and provides the local services for the SEE stick such as route vector and internet access. SEE-phone is the key device for orientation and space awareness; indeed, the SEE-phone communicates with the GPS, through the web server accessing to the map database, and with the others mobile devices. The SEE-phone is always connected to SEE-stick through Wi-Fi.

The SEE-stick is a white cane with a battery of active and passive sensors attached to it such as classic camera, GPS receiver, wheel encoder, ultra son, compass and accelerometer. These sensors will be used for environmental and VIP mobility cues collection and for high level mobility function implementation.

It should be stressed that 6LoWPAN (IPv6 over Low Power Personal Area Network and) and RPL routing protocol are adopted to implement the SEE-stick; therefore, according to the context the SEE-stick can connect P2P with the iSEE and future transportation system [18-19]. Consequently, the SEES system can be considered as an implementation of ITS '*Intelligent Transportation System'* concept.

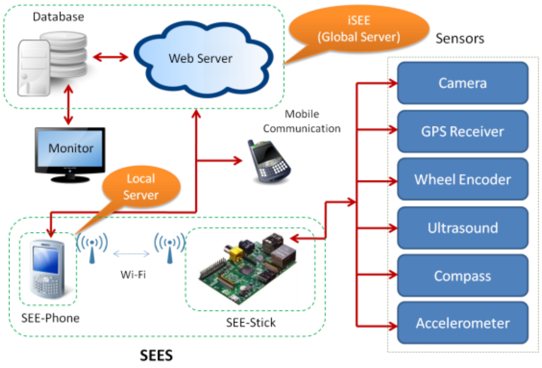

Figure 8. The global concept of SEES system

The SEES possesses the following independent mobility characteristics:

- the VIP can know continuously his/her current location;
- the others person can monitor the VIP's journey and provide a remote assistance, if necessary;
- SEES could be used in the near future by VIP to access urban transportation system (such as car, bus and train) and to GIS (geographic and information system and local detailed maps).

The mobility cues collected by SEES sensors will be transformed into high level space awareness knowledge in order to:

- estimate or predict the status on an object (for example: status of the traffic light or status of the walking surface);
- obtain the accurate location data (what allows to track the user and check if (s)he is on his/her correct way);
- send quickly error/alerts messages to VIP when orientation mistake occurs.

All feedbacks sent to VIP (as a result of multimodal data fusion) are passed via voice or touch stimulation channels.

3.2. SEES support of mobility functions: sensors, considered mobility cues and running models.

SEES targets to assist some walking, orientation and space awareness functions. The considered functions are the most required one by the end-users. For the first SEES prototype, the targeted *space awareness function* is the traffic light status detection; the targeted *walking* functions are the following: obstacle detection, walked distance estimation and surface roughness estimation. The targeted *orientation* functions are: direction to the targeted location estimation and end-user current location/position estimation.

The targeted functions have a direct impact on selected sensors. The status of the traffic lights - a *space awareness function-* is detected by using smart phone *camera* of the SEE-phone (a commercial smart phone).

The walking function is supported by a combination of *ultrasonic*, *camera*, *wheel encoder*, *accelerometer* and *compass.*

The *ultrasonic* sensor is used to detect the obstacles in front of the VIP (e.g. tree, wall, etc.) up to 2m ahead.

The *wheel encoder* sensor is mounted on the SEE-stick wheels; it is then used to estimate VIP travel distance from the starting place. The distance is estimated by combining the data from the wheel encoder, the route vector and the GPS. The travel distance is periodically sent to the local server (SEE-phone) and global server (iSEE) for higher level mobility functions.

The *camera* of SEE-stick is used to detect and recognize the geometry and urban organization of the space (such as road junctions, map of cross section or traffic lights localization).

In association with camera information, *accelerometer* sensor data is used to estimate walking surface roughness so the VIP can adapt their posture. The *compass* sensor is used to detect a moving direction of the VIP. Data from the compass will be integrated with the GPS data and wheel encoder data to enhance the precision of VIP location and distance estimation.

The *camera* of SEE-stick is used to identify and recognize the geometry of the space such as the type of road junctions or map of cross section. Moreover, this camera is also used to detect the traffic lights position.

The *orientation function* will use two main SEE-phone sensors: camera and GPS (includes a Google map). The GPS is used to determine the current location of the VIP, while the Google map allows to plans the VIP’s journey in order to reach his/her spatial target. Periodically the GPS data will be sent to the database server for remote monitoring the VIP, displaying and checking his/her itinerary in real-time. Table 2 summarizes the different sensors and the mobility functions supported by the SEES system.

Table 2. Type and function of sensors

Sensor	SEES System		Mobility Cues (Output Data)
	SEE-stick	SEE-phone	
Ultrasonic	V		Obstacle detection
Wheel Encoder	V		Travel distance
Accelerometer	V		Surface roughness
Compass	V	V	Direction
Camera	V	V	Obstacle/object status /space geometry
GPS	V	V	Location/position

The mobility cues will be the inputs to the SEES layer which will transform them into high level knowledge useful for mobility; this knowledge will be directly conveyed to the VIP (a feedback).

3.3. SEES Running Models

SEES is a 3-module system (SEE-stick, SEE-phone and iSEE) with WIFI data transmission between the SEE-phone and SEE-stick. SEES has several working modes in function of the SEES hardware configuration. Table 3 shows all SEES modes. It is possible to switch from one model (assistance level) to another during the operation if the appropriate hardware is available.

Table 3. SEES operational modes

Mode	SEES System			Description
	SEE-stick	SEE-phone	iSEE	
Mode 0	V			Basic mode
Mode 1		V	V	Phone mode
Mode 2	V	V		Local mode connection
Mode 3	V	V	V	Complete mode

The SEES interface to VIP offers four assistance levels (operational models):

1) *Mode 0* is always active as it is the SEES minimal hardware configuration; only the SEE-stick is active - the SEES system becomes a SEE-stick.
   This mode will allow the VIP to walk without a smartphone. The walking will be assisted by stick sensors provided data (GPS, ultrasonic, camera, encoder, accelerometer and compass sensor).
   The main drawback of this mode is that the VIP can not receive any confirmation/information (or calls his/her friend/family) in relation to his/her journey progresses (correct or wrong). However, it is possible that SEE-stick connect to the iSEE through Wi-Fi access point when need (opportunistic routing);
2) In the *Mode 1* -phone mode- the SEES works by using the SEE-phone and iSEE. This mode will allow a user to move without a smart. The mobility will be assisted using smartphone sensors (GPS, camera and compass) and iSEE server.
   The drawback of this mode is that the VIP can not detect neither obstacles nor the roughness of surface;

3) *Mode 2* -local mode- makes SEES working with both its subparts, SEE-phone and SEE-stick. The SEE-stick cooperating with the iSEE server and the SEE-phone is used only as a router (Wi-Fi access point) to overcome the mobility difficulties. The VIP can get a remote help from persons who monitor the server. In this mode, the SEES provides the selected travel specific hints and advices;
4) *Mode 3* -the complete mode- makes SEES working with all its sub parts (SEE-phone, SEE-stick and iSEE). The SEE-stick cooperates with the SEE-phone and iSEE to overcome the mobility difficulties. The VIP can get a remote help (from relatives using the telephone (mobile communication) or the others person who monitor the server. In this mode, the SEES provides the selected travel specific hints and assistance.

IV. EXPERIMENTAL PRELIMINARY EVALUATIONS OF SEES SYSTEM SOME FUNCTIONS.

As the SEES system is an association of two subsystems, SEE-Stick and SEE-Phone, preliminary experiments have been realized in order to estimate their technical performances: basic navigation with SEE-stick prototype (4.1) and basic space awareness function –traffic light status recognition – for SEE-phone/smart phone (4.2).

4.1. Experimental technical preliminary evaluation of SEE-stick prototype.

Basic walking assistances were implemented in SEE-stick prototype: it aims to track the VIP walking on a standard route, i.e. route, which consists of sidewalks and cross-streets (figure 9). The ideal navigation (reference) route started in one yellow point and continues through yellow path to another yellow point.

Three methods for track generation have been evaluated and compared the generated track accuracy:

- the RISS-GPS-LKF based on RISS (Reduced Inertial Sensor System)/GPS integration which we improved with the Linearized Kalman Filter (LKF) [20], (which generated the optimal track),
- the RISS/GPS integration method with GPS only (GPS track), and
- the RISS only (*Dead Reckoning*, DK track).

The tracking lines obtained by the three methods are shown in Figure 9. The yellow line is the reference navigation route; the red line (the optimal track) is given by RISS-GPS-LKF integration method; the green line corresponds to DK estimated navigation route and blue track is a GPS track.

The RISS-GPS-LKF integration method, comparing with GPS and DK methods, provides the best estimate of VIP's track.

Figure 9. Experiment 1 of navigation accuracy validation

The first experiment with the VIP was done under a clear sky condition without GPS outage and without the VIP knowing the route in advance. The system provided an audio feedback to the VIP in order to keep him/her walking on the track estimated by the RISS-GPS-LKF algorithm.

During the walking process, the system checks if VIP’s trajectories and headings agree with navigation route. The angle between VIP's heading and the sub-route's direction should be less than 45°. If the angle is great than 45° for a short period (e.g. 3s), the system tells the VIP the angle between his/her heading and the route direction and asks the VIP to adjust his or her heading.

4.2. Experimental technical preliminary evaluation of SEE-phone.

Two functions have been implemented in SEE-phone which are useful for assistance for the VIP space awareness assistance: color detection using smart phone (for traffic light status recognition) and remote route tracking (for continuous check of the VIP itinerary).

Experiments have been implemented on Android emulator system (running on personal computer) and on smart phone [21]. For traffic light recognition a camera of smart phone Samsung SIII Model GT-I9300. The whole process can be summarized as follows:

- capture the color image of the traffic light;
- calculate the average of HSV (a reference data) of the captured image;
- when the value of the colors (traffic lights) captured by the SEE-phone camera is in the range of reference data, the voice application -TTS (*Text To Speech*) generates an audio message : “*red stop here*”, “*yellow slowly run*” or “*green please run away*”.

The results of the traffic light status detection are displayed in figure 10. The upper images (left to right) are signs of traffic lights status for pedestrian. The lower images (left to right) show results of color detection by SEE-phone. In this experiment, android application program detects three colors: red, yellow and green.

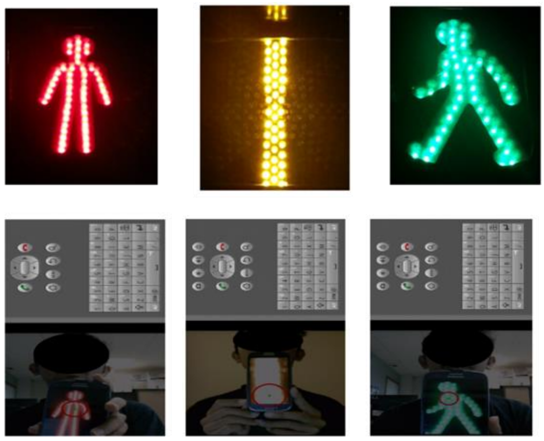

Figure 10. The color detection on android emulator

V. CONCLUSION

This paper has introduced the concept of the SESS, a space explorer smart stick, for the visually impaired mobility assistance, and its first prototype design. This concept is based on -the space awareness and orientation capabilities - key elements for (the VIPs) independent mobility.

The architecture of the SEES system, an example of SESS, has been proposed; it integrates three sub-systems which complements each other: iSEE, SEE-phone (based on a commercial smart phone) and SEE-stick (based on the white cane).

The realization of a SEES involves various sensors which work and cooperate simultaneously such as ultrasonic sensors, visible spectrum cameras, compass sensor, accelerometer sensor, wheel encoder sensor and GPS receiver. The SEES system preliminary evaluations for the VIP tracking while walking in simple scenarios and for traffic light status recognition have been successful; the real track provided by the RISS-GPS-LKF algorithm was close to the reference track and the traffic light status was correctly recognized.

Future works will tune the proposed SEES overall design, will add and modify assistances, will evaluate its technical performance and will design a pilot studies which will involve the targeted population with different degrees of visual impairment (participative design).

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