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Research paper

Topography analysis using wearable devices and its integration in navigation systems

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Abstract

Automatic navigation in an unknown environment raises various challenges as many cues about orientation are difficult to perceive without the use of vision. Though assisted aids such as GPS devices help in route finding, still it fails to fulfill safety requirements. This paper proposes a framework that provides accurate guiding and information on the route traversal and the topography of the road ahead. The framework is composed of technologies such as Lumigrids, Drone, GPS, Mobile applications, Cloud storage which are used to map the road surface and generate proper navigation guidance to the end user. This is done in three stages; [1]. Off-line mapping of the road surface and storing this information in the cloud. 2. Wearable technology used for obtaining in real-time surface information and comparing it to the data on the cloud facilitating accurate and safer navigation 3. Updating the cloud information with information collected by the pedestrian

Keywords: *Navigation; Topography; Computer Vision; Wearable Technology; Mobile*

1. Introduction

There are many technological navigation aids like city maps and GPS navigators. But they all don't focus on pedestrian paths. Surveys show travelers require detailed information about the terrain and its challenges – size, curves, hurdles, fences, changes in elevation etc. [1]. This paper proposes a three-phase safe navigation system that provides surface information of the pedestrian paths and use this information while suggesting in real time routes to the visually impaired/

2. Literature review

Most applications use location-sensing technology such as GPS combined with a map to locate and guide pedestrians. MOBIC dialogue system introduces multi-tiered directions that provide progressively more detailed information about a scene [9]. Recent work has found that visually impaired individuals using navigation devices travel to new areas faster [4] and with less errors and halts [5] than using

Physical maps or direct experience. Sendero [6] uses smart phone's location sensing power. Trekker Breeze [7] supports orientation using a commercial GPS receiver. Other works suggests computer vision based systems to recognize and locate traffic crossings, lights, and signals [14]. Recent work has combined crowd sourcing with computer vision techniques to provide additional information about traffic intersections [2] and sidewalks [15], or arbitrary images [16]. Few open source [17], [18] software systems provide similar navigation instructions on points of interest like restaurants and buildings to the user using speech or Braille output. Studies say that pedestrians are positive on using technological assisted aids to guide them for navigation [19]. Advantages of using automated technological navigational aids for the visually impaired are mentioned in [11].

3. Detailed design

The proposed navigation system consists of the following three phases:

1) Terrain mapping phase
2) Pedestrian guidance phase
3) Re-mapping of the terrain based on comparative walk-thru and Terrain database

In the terrain mapping phase, an unmanned aerial vehicle is made to fly over the pedestrian path. This vehicle records the GPS coordinates of the mapped region and accurately identifies the actual terrain of the underlying pedestrian path. This data is versioned and stored in a cloud. This referential database is centrally shared for the visually impaired.

The terrain mapping phase is essential to initially map all the pedestrian paths and populate the cloud with data.

The Pedestrian guidance phase is the phase where the stored terrain related information on cloud is combined with the regular GIS/GPS based route finding [10] and in real-time is used to guide a pedestrian in navigation. A shirt mounted device assists the visually impaired in achieving this. During the walk-thru the mounted device with the visually impaired obtains the real-time terrain information of the path ahead and compares it to the existing information on the cloud to alert on the new challenges / hazards that may have cropped up.

In case during the walk-thru by the visually impaired if the terrain poses new challenges, this information needs to be updated in the central database and require remapping as appropriate. Re-mapping can also be triggered by on-need basis.

4. The navigation system

4.1. Components of the terrain mapping phase

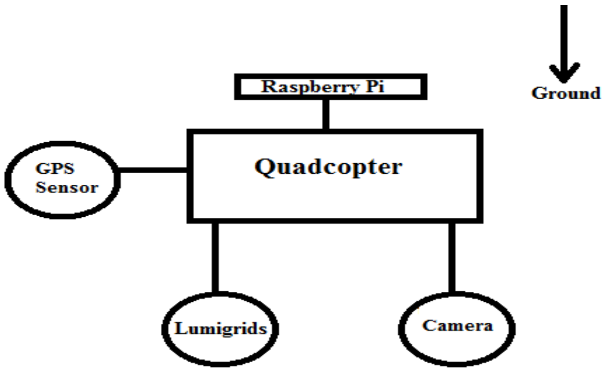

Fig. 1: Components Used in Terrain Mapping Phase.

The terrain-mapping phase consists of the following components: Quadcopter - unmanned aerial object. Raspberry- a microcomputer to run required image processing algorithms and save the information to the cloud. Lumigrids-a LED projector projecting light in the shape of grids as follows:

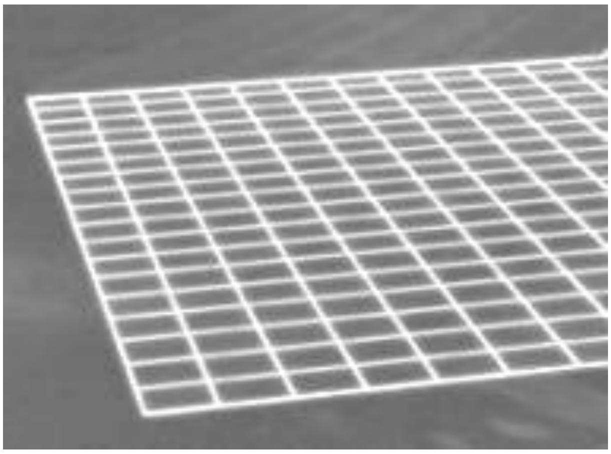

Fig. 3: Light Grids Projected by Lumigrids LED.

Lumigrids are mounted on the quadcopter and placed facing the ground. These light grids can accurately extract the terrain information of the pedestrian path as the regular arrangement of the lights grid gets distorted based on the terrain [15] shows how lumigrids can help cyclists to understand the terrain ahead at night and keep them safe.
Camera - placed facing the direction of ground where the lumigrids is projected. It constantly takes the images of the patterns formed by the grids and sends it for image processing. GPS sensor-used to obtain the GPS location of the quadcopter drone
Raspberry Pi serves as the central computing unit for all the attached sensors. It processes the captured images of the formed light grids on the ground and obtains the required terrain information
An interesting approach mentioned in [10] can also be used to obtain the terrain related information by using the accelerometer data of the smart phones of the other visually sound pedestrians who use these pedestrian paths. The accelerometer of their mobile devices detects the vibration along the X, Y and Z-axes. The magnitude m of the acceleration is calculated as $m = \sqrt{X^2 + Y^2 + Z^2}$ This is used to predict the terrain information of the pedestrian paths.

5.2. Pedestrian guidance phase components

1) A smart phone application like [6] which continuously transmits the GPS location and orientation of the pedestrian to the cloud and obtain the data about the terrain of the path ahead of the pedestrian.
2) A shirt mounted unit attached physically to the pedestrian. The unit consists of a lumigrids projector, camera and a communication unit. The lumigrids unit flashes the lumigrids on the ground and the camera captures the images of lumigrids formed and continuously transmits the images to the smartphone application of the pedestrian.

Solution Architecture

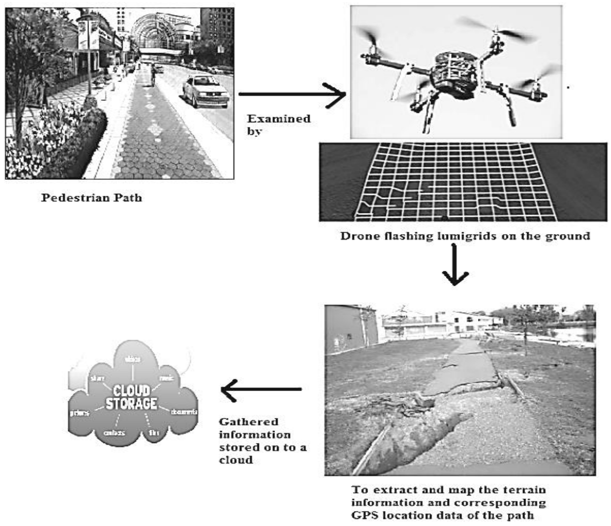

Fig. 5: Working of the Terrain Mapping Phase.

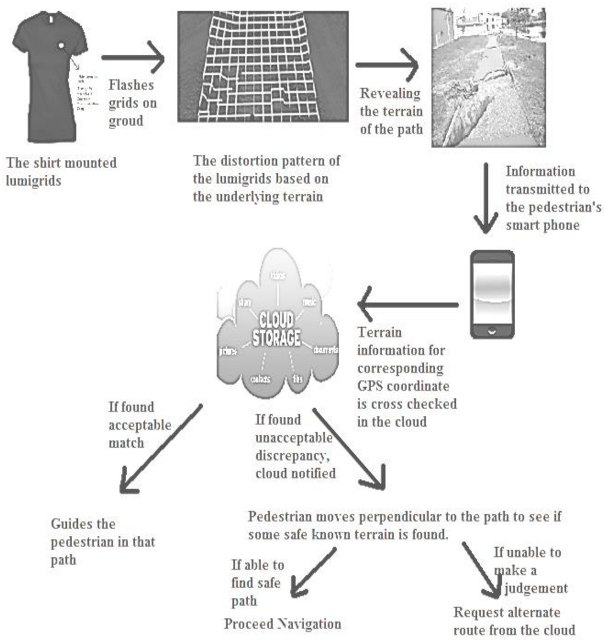

Fig. 6: Working of the Pedestrian Guidance Phase.

Working
The terrain mapping system consists of the lumigrids and GPS sensor mounted on a quadcopter flies along the pedestrian path at height "h" above ground.

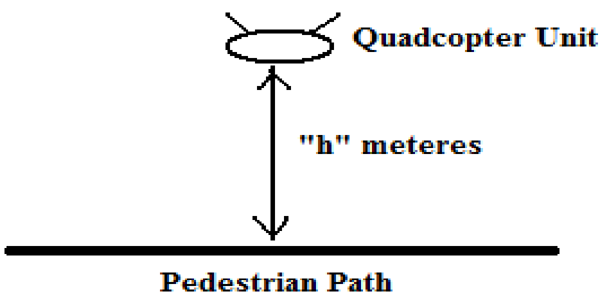

Fig. 7: Quadcopter Flying for Terrain Mapping Phase.

The steps of the terrain mapping phase:

1) The entire pedestrian path is divided into squares of equal area – called the sub-squares: Let "k" be the area of each sub-square with side "x" which are named as (1, 1), (1, 2) and so on.
2) The height "h" is adjusted to generate lumigrids of area "k" just enough to cover each sub square.
3) The midpoint M of the sub-square is calculated as:

$$M = (lat1 + \frac{x}{2}, long1 + \frac{x}{2})$$

4) The quadcopter flying at height "h" above the ground files to the calculated M from where it flashes the lumigrids of area "k" equal to the area of the sub-square on ground. The lumigrids projector creates the light grids of dimension nxn on the ground below.
5) The following image formed on the ground shows an undistorted lumigrids of area "k" formed on an ideally flat and perpendicular surface to the quadcopter flying at a height "h" above the ground.
6) The mounted camera captures this image and thresholding [13] of the input image splits the lumigrids image data from rest of the image as explained in 10. Camera coordinates can be mapped to the real-world coordinates by the following transformation matrix

$$\begin{pmatrix} Xc \\ Yc \\ Zc \end{pmatrix} = Tcm \begin{pmatrix} Xa \\ Ya \\ Za \end{pmatrix}$$

Where (Xc, Yc, Zc) are the coordinates of the object in camera and (Xa, Ya, Za) are the coordinates of the same object in real world and Tcm is the transformation matrix which can be calibrated for a camera. [12]

7) The dimensions and inclinations of each line segment of the nxn segmented sub-square are the parameters used to represent an ideally flat terrain $Length(= Breadth)\ of\ each\ side = \frac{x}{n}$ Inclination of each side=90°
8) Shortening of length (less than $\frac{x}{n}$) of any line segment (even skewed) of the formed lumigrids square mesh indicates that the terrain beneath the formed lumigrids is not flat. It is either concave or convex in nature along the Z-axis.
9) The angle between the line segments (tangents of the line segments at the point of intersection if they are skewed) if not right angle indicates that there is an inclination in XY plane of the terrain beneath the formed lumigrids based on the quadrant (1st quadrant or 4th quadrant) of inclination. Let a' be the inclination of the line segments of the lumigrids and "a" the corresponding inclination in the ground is given by: $a = \pm d1 * a'$

Where "d1" is the ratio of the inclination on the ground and the corresponding inclination caused by the lumigrids. In addition + indicates that the inclination is towards the first quadrant and – indicates that the inclination is towards the fourth quadrant.

Where "d1" is the ratio of the inclination on the ground and the corresponding inclination caused by the lumigrids. In addition + indicates that the inclination is towards the first quadrant and – indicates that the inclination is towards the fourth quadrant.

10) After the image thresholding algorithm on the obtained image, the lumigrids are visible clearly as

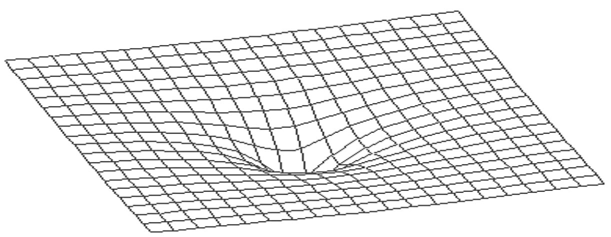

Fig. 12: Lumigrids Formed Over A Pit.

In the above image, the required lengths as in Fig. 10 between the skewed line segments are calculated.

11) Let a line segment of generated lumigrids of ideal expected size $\frac{x}{n}$gets shorten by ypercentage due to a skewed terrain. Let "d2" be the ratio of the absolute value of the vertical height on the ground indicated by the corresponding lumigrids to length of the corresponding line segment generated by the lumigrids. Then the absolute height "h" with reference to ideal flat surface of the ground is given by

$$h = \pm d2 * \frac{x}{n} * \left(\frac{100-y}{100}\right)$$

Axiom 5, decides if h is positive or negative. h is positive for concave terrain and negative for convex terrain. If y=100%, theoretically there could be a narrow pit or hill in the ground, as indicated by the non-visibility of the lumigrids.

12) To exactly identify if the terrain at a given position is concave or convex in nature, we observe the inter line segment distance i of the terrain:

If i = $\frac{x}{n}$ =>Flat surface, If i>$\frac{x}{n}$ =>Concave surface, If i<$\frac{x}{n}$ => Convex surface

13) After calculating the terrain information of the given sub-square, the process is repeated to all the sub-squares so that the entire pedestrian path is scanned for its terrain details and mapped. The data thus obtained is pushed to the cloud.

The cloud now has precise information of the terrain. The pedestrian guidance phase consists of the following steps:

1) When the pedestrian wishes to navigate, the pedestrian's smart phone requests a route from source to destination. A GIS map [10] is consulted to obtain various routes from the source to the destination. The data from the cloud has precise information about the terrain of each of the pedestrian paths present in all these routes. An optimum route is selected based on the variations in the terrain in that route, pedestrian traffic density in the route, route with easy help in case of danger or need and various other parameters which govern the safety of the pedestrian are considered.
2) The smart phone guides the pedestrian along this route in the pedestrian path. All major terrain variations in the pedestrian path are alerted to the pedestrian.
3) The shirt mounted unit on the pedestrian flashes the lumigrids on the path ahead and the camera embedded on the unit captures the image of the lumigrids formed and transmits this image to the smart phone of the pedestrian

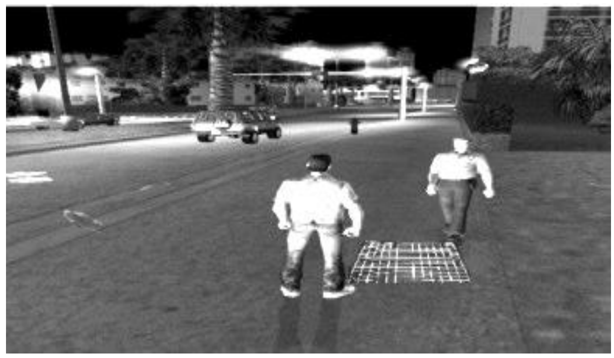

Fig. 14: Lumigrids Formed by the Shirt Mounted Unit of A Pedestrian in the Guidance Phase.

4) The terrian information obtained from the lumigrids are cross checked at real time with the terrain information available in the cloud to recognize and handle temporary terrain changes, like dog sitting on the pedestrian path or a random stone in the way, or sudden permanent terrain changes like a road block.

5) If considerable discrepancies are found in the terrain, the person is alerted to find possible alternate route like "Stop and Move 3 feet to your right" and a match for the known pattern in cloud is checked for. If a match is found, the pedestrian is guided along that path.
6) If some permanent blocks are identified by the shirt mounted device, the cloud is notified about this so that the cloud can flag the terrain data of that pedestrian path as obsolete and can schedule a re-mapping of the terrain phase. An alternate route is found for the pedestrian and the pedestrian is guided accordingly.

Re-mapping of the terrain based on comparative walk-thru and Terrain database phase consists of re-mapping of a pedestrian path either if the current data is flagged as obsolete by the pedestrian guidance phase, or a scheduled re-mapping process or on-need basis.

Data Structure

The data on cloud contains the terrain information of the pedestrian path capable of generating a terrain grid along with its GPS coordinates.

The visualization of the data represented as terrain grid available on the cloud for a pedestrian path looks like the below figure:

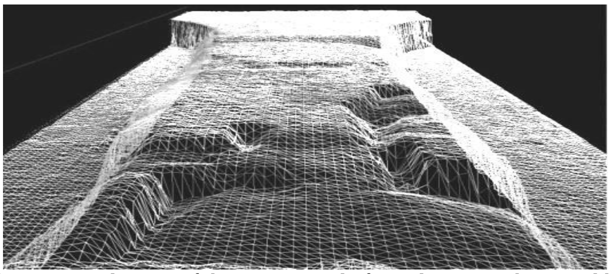

Fig. 13: Visualization of the Terrain Grid of a Pedestrian Path Formed by the Data on Cloud.

1) A Sample Data from the Cloud is as Follows GPS – the coordinates of the GPS location, Ver. – The Version number of the data, h - The height of the terrain, a - The inclination of the terrain, Dirty Bit- Specifies if the data is obsolete

GPS	Ver.	h	a	Dirty Bit
(20,30)	1	+20	-3	0
(20,31)	1	+20	-7	0
(20,32)	1	+20	-10	0
(20,33)	1	+20	-10	0
(21,30)	1	+2	0	0
(21,31)	1	+2	+1	0
(21,32)	1	+3	0	0
(21,33)	1	0	-2	0
(20,30)	1	-8	0	0
(20,31)	1	-8	0	0
(20,32)	1	+2	0	0
(20,33)	1	+2	0	0

2) When the pedestrian wants to navigate, he first initiates a session with the cloud server, which is a onetime activity for every navigation session.
3) The smart phone application now starts streaming the terrain data from cloud shown above which is the reference data of the pedestrian path
4) The system guides the person to follow the route and alerts on any terrain related danger. For instance, when the pedestrian is in (20, 33). The interface alerts the pedestrian that there is a pit right in front of him ((20, 30), (20, 31) as indicated by a negative high value) and identifies that nearby terrain is tolerable to walk and guides the pedestrian accordingly.
5) The lumigrids on the shirt scans the terrain ahead of the person and checks if there is an acceptable match with the reference data on cloud. If there is any discrepancy in the data obtained by the shirt and the cloud, the person is requested to take some alternative like a slight lateral movement and again a match is checked for. If the person is not able to get any help or no match is found, the server looks for alternative routes and guides the person. For instance, let the person be in (21, 30). According to the cloud data, there should be a high wall in front of him, but the shirt mounted unit scans and finds that there is no wall now and the terrain is optimum to walk. It flags all these data in the cloud as dirty by setting the Dirty Bit as follows:

GPS	Ver.	h	a	Dirty Bit
(20,30)	1	+20	-3	1
(20,31)	1	+20	-7	1
(20,32)	1	+20	-10	1
(20,33)	1	+20	-10	1

According the cloud decides if it needs to schedule a re-mapping phase for that terrain or to accept the information shared by the pedestrian shirt.

After the re-map, following is the data in the cloud:

GPS	Ver.	h	a	Dirty Bit
(20,30)	2	+0	0	0
(20,31)	2	+2	0	0
(20,32)	2	+0	0	0
(20,33)	2	+2	0	0

5. Conclusions

This paper proposes a conceptual framework which fills the major gaps exist in the design of technological navigation aids and explains the software architecture, hardware and wearable devices requirements and the theoretical models necessary for building an infrastructure to seamlessly gather the terrain related information of the pedestrian path and use this information to guide the pedestrians to navigate properly.

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