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A PROTOTYPE TWO DIMENTIONAL TRACKING NAVIGATION SYSTEM BASED ON DEAD RECKONING TOOLS

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ABSTRACT

Most Recent researches of Land Vehicular navigation systems focus on using Global position System (GPS) integrated with Inertial Navigation System (INS), which depends on a large size tools and of high cost. Recently, traditional (INS) instruments has been modified and developed by a new technology known as Micro Electro Mechanical System (MEMS). This research aims to create an alternative independent navigation system of low-cost and locally available components to give a suitable precision for navigational works. This system consists of (rotary shaft encoders) as sensors, for measuring distances and directions, instead of the accelerometers and gyroscopes used in the INS. Several preliminary experiments had been made, where, the obtained results were modest. To improve the precision of these results, data were processed through a program designed especially for this purpose, where two closed loop experiments were conducted at nearly horizontal plane areas, the first experiment was a loop of about 200 m length and the second had an approximately 800 m loop length. The closing errors of the two loops were about 1:80, which is considered acceptable for an initial prototype system used for navigation works. Therefore, the final results of this research showed that the (Rotary shaft encoders) had been used as a main part of a simple dead reckoning navigational system, which means that the shaft encoder was used for measuring distances and measuring directions for the first time.

Key words: Dead reckoning; INS; Navigation systems; Shaft encoder Sensor

1. INTRODUCTION

Navigation is the continues processing of reading a vehicle movements (distances and directions) for computing the continues positions of the vehicle at all points along its path [3]. Nowadays, the most popular navigation technology used is the Global Position System (GPS), because of its high accuracy in position determination [1], [2]. However, GPS-based vehicular navigation systems are subject to severe degradation performance in environments that are characterized by frequent GPS outages (complete/partial). To overcome this limitation, GPS is often integrated with an Inertial Navigation System (INS) [6], [8], [10]. Traditional (INS) uses precise gyro and accelerometer sensors. The high cost and large size of inertial units are the main obstacles for their inclusion in precise navigation systems to support a variety of application areas, however, recently newer inertial devices with compact but lower precision sensors exist in the market, unfortunately they still have moderately high cost. This group of instruments is called motion sensors or Inertial Measurement Unit (IMU) [12]. Several studies in the last few years have focused on the integration between IMU-based INS (herein referred as MEMS INS) and GPS, for instance [4], [7], [9], [11], and [13]. However, many of these studies have focused on evaluating the performance of these systems under better operational conditions (open sky). This paper introduces a new created-local navigation positioning system using Rotary Shaft Encoder sensor as a dead reckoning tool. These encoders are considered as an electro-mechanical device that converts linear or rotary displacement into digital or pulse signals [5]. The encoder consists of a coded rotating disk, a light source, and a photo detector (light sensor). The disk is made of metal, plastic or glass, which is mounted on the rotating shaft, has patterns of opaque and transparent sectors coded into the disk, figure (1).

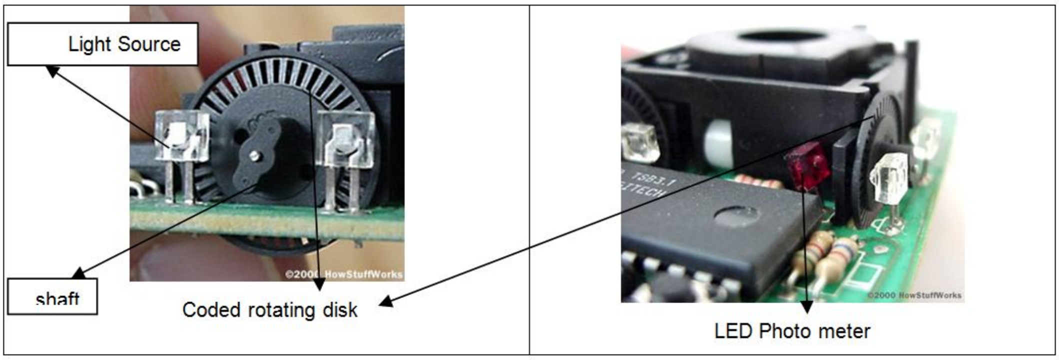

Fig. 1. *Shaft encoder*

The calibration tests had been done twice, first the calibration was made in lab and the second time in the field. The created new system was tested in two places. The first place (study area1) was selected inside SHOUBRA Faculty of Engineering (SHOUBRA district – Cairo – Egypt) with 65 m length. The route which was selected at that area in the initial experiment was recorded by the system completely different, this problem was solved through two ways (hardware and software), as will be shown later. The second place (study area2) was selected outside in the surrounding area of the faculty to permit longer loops, where two experiments were made with lengths 200 m and 800 m. The losing errors of the two loops were about 1:80, which is considered accepted relevant to an initial prototype system.

2. COMPONENTS OF THE NEW CREATED NAVIGATION SYSTEM

The new created navigation system is composed of the following components:

- A Bike used as a simple vehicle, figure (2).
- Two Shaft rotary encoder (sensors) from (NUX-HANYOUNG) model (HYRA-A), one is used for determining distances, have 500 pulses or divisions and the second is used for defining directions, have 360 pulses [15], figure (3).
- A Data acquisition card (DAQ), (NI USB-622x M Series), figure (4).
- A portable laptop computer (Compaq Presario CQ61), supplied by LABVIEW software to process the encoder signals, figure (5).
- Batteries 12 Volt.

Fig. 2. *Vehicle*

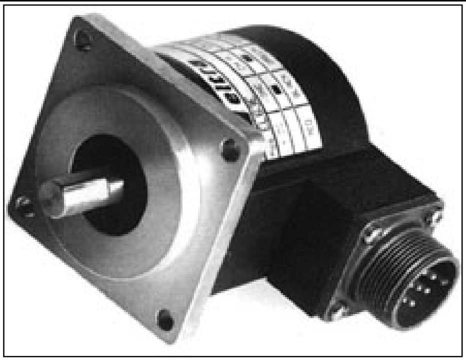

Fig. 3. *Shaft Encoder*

Fig. 4. *Data Acquisition card (NI USB-622x M Series)*

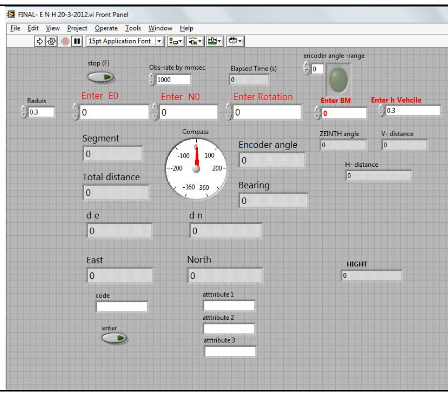

Fig. 5. *Labview interface*

3. CONFIGURATION OF THE SYSTEM

One of the major tasks of the system is to count the electric encoders pulses and convert them either to distances or directions. For the counting purpose the body frame of the encoder is connected to the static body of the used bike and the rotation part "axis of encoder" is connected to the movable part of the used vehicle. Thus for the directions computation, the axis of the direction's encoder is connected to the axis of the steering part of the bike, figure(6), therefore any movement in the direction of the steering part will be sensed directly by the shaft encoder, positive for clockwise direction and negative for the anticlockwise direction. The LABVIEW software will cumulatively count the number of the electric pulses and converts them instantaneously into directions. For the distances computation the axis of the second encoder is connected to an additional gear having the same diameter and number of teeth of the main gear and placed between main gear of back wheel and pedal, figure (7) therefore, any rotation of the back wheel will be sensed directly by the encoder and convert it into number of electric pulses by the LABVIEW, then the moving distance is computed instantaneously based on the circumference of the back wheel.

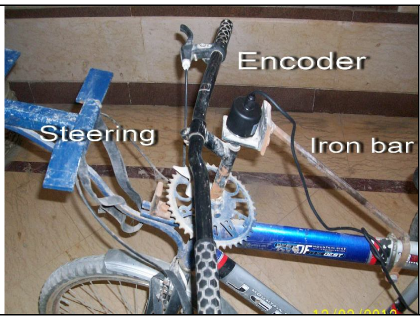

Fig. 6. *Direction sensor*

Fig. 7. *Distance sensor*

4. MODEL ALGORITHMS

The computation of the navigation positioning path of the proposed dead reckoning system can be obtained by using figure (8), where.

P(0): initial position of vehicle.
P(i): position of vehicle at point (i).
E(i): Easting coordinates of vehicle in meter at point (i).
N(i): Northing coordinates of vehicle in meter at point (i).
d(i): Partial distance between point (i) and (i-1).
αi: Computed azimuth of vehicle at point (i).
i: Is an integer relevant to the observational time, from {1, 2, 3,………………n}, where (n) is the final observational time in seconds.

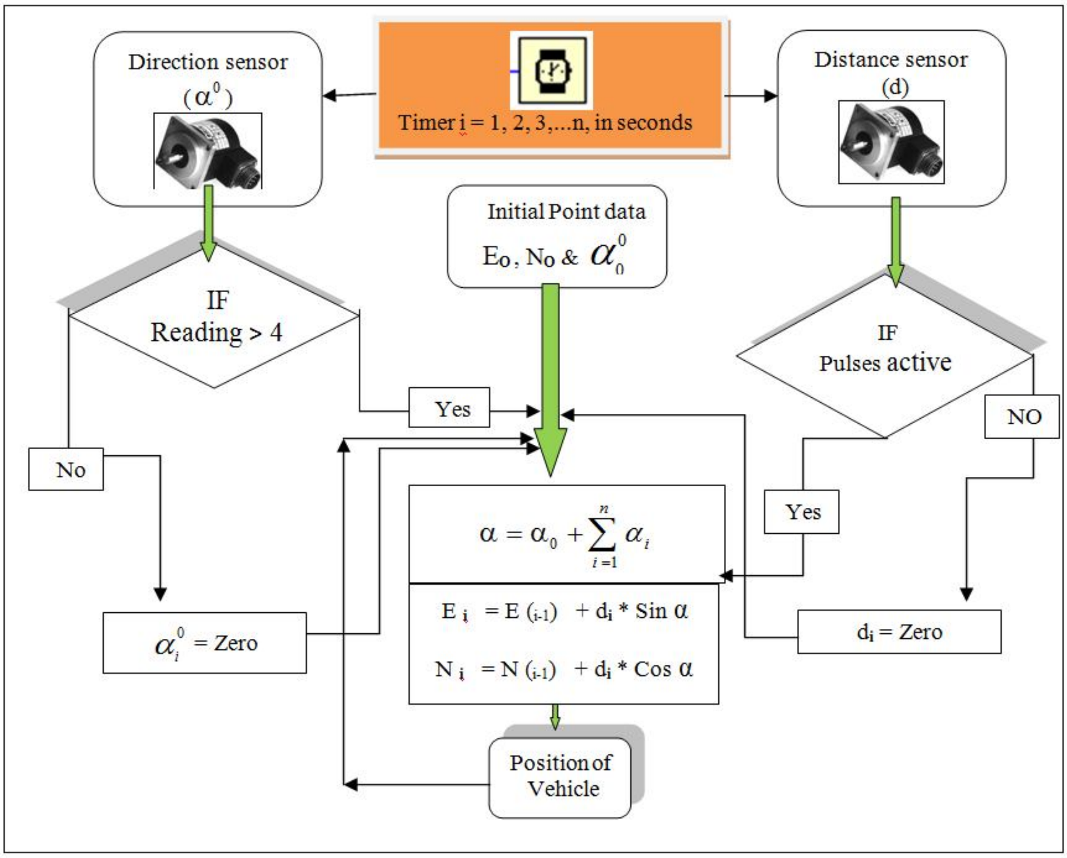

Fig. 8. *Flow chart*

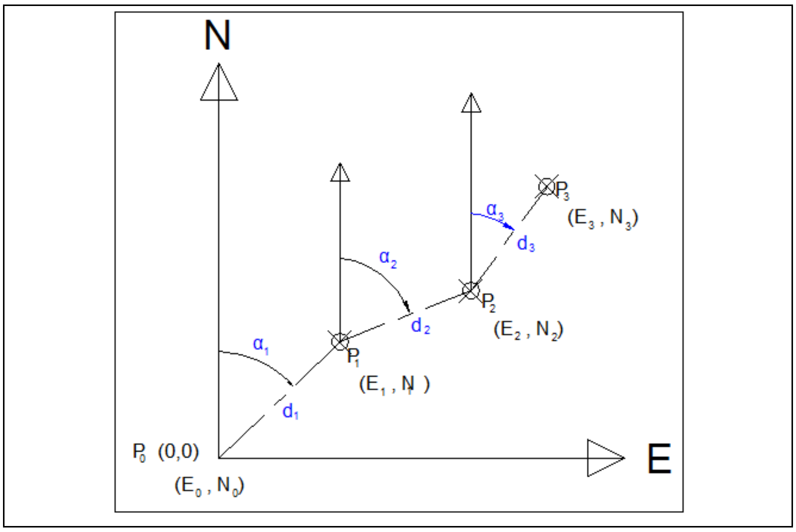

Fig. 9. *Coordinates system in two dimension*

5. METHODOLOGY

5.1. Calibration of shaft encoder

The calibration is made in two steps as follows:

5.1.1. Lab Calibration

The purpose of this simple calibration was to check the exactness of encoder's readings. This had been achieved by drawing a circle divided into known equal parts on a sheet of paper; as for example in our case eight equal parts representing the 360 degrees of the complete circle readings; as (0, 45, 90, 135, 180, 225, 270, 315), figure (10). The shaft encoder was connected to a DAQ (having specification given in [14]) to convert the rotation movement of the encoder axis into digital number " angular position α° ".

$$\alpha^\circ = \frac{\text{The output signals from encoder} \times 360^\circ}{\text{Max. pulses number of used encoder}}$$

This angular position is shown on the screen interface of the software LABVIEW, figure (11). The experiment was repeated ten times for each encoder's reading. where their mean and standard deviations, are shown in table (1).

Table 1. Data readings of the 500 & 360 pulses shaft encoder

	Encoder 500 pulses		Encoder 360 pulses	
Actual Reading	**Mean = (∑ / 10)**	**± st.dev of reading =** $\sqrt{VV\ /(9)}$	**Mean = (∑ / 10)**	**± st.dev of reading =** $\sqrt{VV\ /(9)}$
45.000	**45.214**	**0.202**	45.358	0.362
90.000	**90.283**	**0.348**	90.442	0.332
135.000	**135.249**	**0.256**	135.321	0.333
180.000	**180.257**	**0.287**	180.388	0.337
225.000	**225.368**	**0.297**	225.362	0.350
270.000	**270.281**	**0.321**	270.250	0.335
315.000	**315.219**	**0.231**	315.378	0.259
0.000	**0.1707**	**0.266**	0.353	0.477
	Mean st.dev.	0.276	**Mean st.dev.**	**0.348**

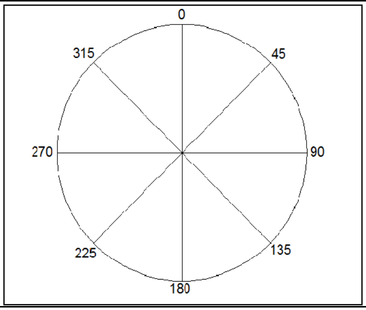

Fig. 10. *Calibration sheet of sector angles*

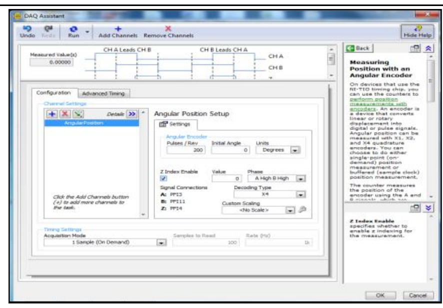

Fig. 11. *Labview interface sofware for data aquisition*

5.1.2. Field Calibration

Several experimental tests were made in straight line path within the parking area of SHOUBRA faculty of engineering to check the data of the composed system. The experimental tests were made in a completely smooth flat path (on a marble floor of a corridor) between two points 13 m apart. The wheel radius of the used bicycle was measured and the starting point (tangent point between the wheel and floor) was marked, the bicycle was then moved tell the end point of the path, The recorded distance made by the bike where then viewed through Lab View software. The experiment was repeated 10 times with stander deviation ± 0.026 m.

5.2. Verification of the proposed system and adjustment of the primary obtained results

For the verification and adjustment purposes of positions obtained from the system, the following steps were made:

- Preliminary experiment of broken straight lines having 65m length.
- Identifying problems founded in the path.
- Determination of different sources of errors in the experiment.
- Procedures of system treatment to reduce the errors.
- Assessment step was made through two experiments in the second test area, in closed loop path of 200 m and 800 m lengths.

5.2.1. Initial experiments

- After the straight line calibration tests had been made, four points in the same area were marked to represent a new path of broken straight lines having 65m length, figure (12), which were observed and recorded by total station. More than 20 tests had been made in the new path. Figures 13 (a, b, c, d, e, f) represent only six of those tests as a sample, three of these tests were made in forward direction (from the first to the fourth point, figure13 (a, b, c).
- and the other three in backward direction (from the fourth to the first point, figure13 (d, e, f) where the solid broken straight lines represent the original designed path, while the dotted lines / curves represent the path recorded by the proposed system during the initial tests.

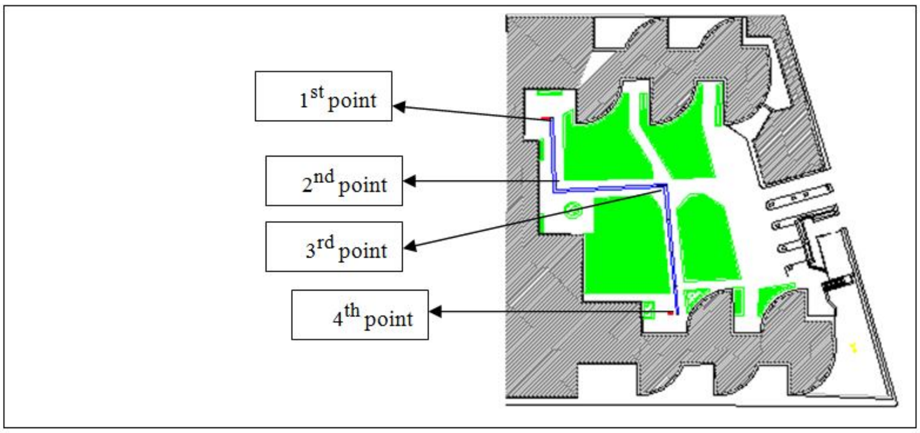

Fig. 12. *Study area1-Faculty of engineering –Soubra(path length 65m)*

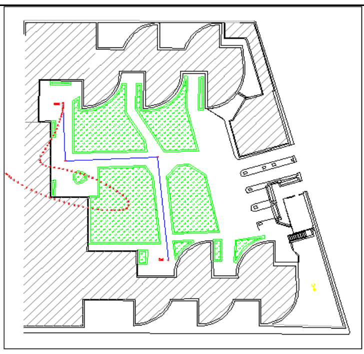

Fig. 13.a. *Forward Dirction*

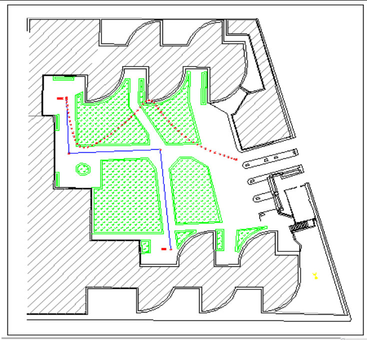

Fig. 13.b. *Forward Dirction*

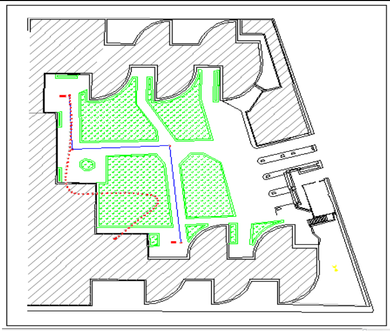

Fig. 13.c. *Forward Dirction*

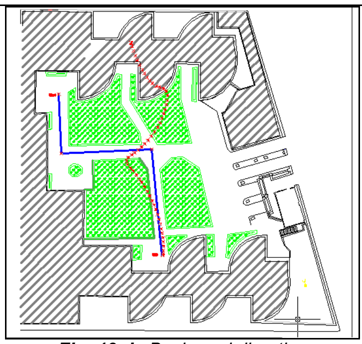

Fig. 13.d. *Backward direction*

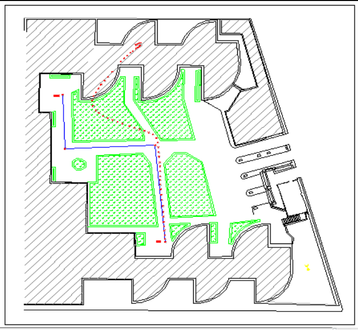

Fig. 13.e. *Backward direction*

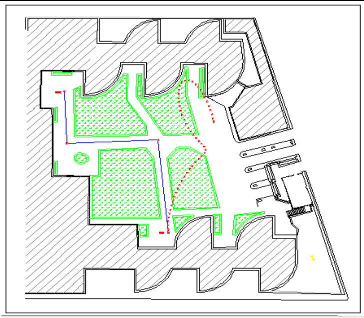

Fig. 13.f. *Backward direction*

5.2.2. Identifying problems in the preliminary experiments

After the experimental tests had been made in the first study area, the results showed great deviations from the designed path. The deviations were divided into the following categorize:

- The straight lines appeared as curves due to the cumulative error emerged from vibration of the vehicle steering.
- The recorded curved paths did not take the same designed paths.
- System position was continuously changing in spite of vehicle in-rest, due to additive repetition of the last sensor readings of distance and direction.

5.2.3. Determination of different error sources in the system.

Investigating the final results of the experiments, the deviations in the recorded path could be due to the following:

- Sensitivity of sensors.
- Stability of the vehicle.
- Motion type surface.
- The observational time rate and speed of vehicle especially in curves.

5.2.4. Procedures of system treatment to reduce the errors

The initial experiments were made by using an encoder of 500 pulses for direction measurements, while a 360 pulses encoder was used for distance measurements. The recorded path of these experiments was completely out of range as shown in figures 13 (a, b, c, d, e, f). To reduce the produced errors in the shape of the path, the two encoders used in the system were exchanged essentially to decrease sensitivity of direction's encoder.

To reduce the vibration effect of the steering on the shape of the recorded path, a simple software was designed to neglect any direction reading within range (± 4°) to filter out the cumulative errors emerged from the vehicle steering vibrations. In this way the created system had been obliged to record the designed straight path as it is, as shown in figure (14).

In the stopping case of the bike, the encoder axis does not rotate, and the sensor of the distance should not send any pulses, however the system still counting and adding the last reading cumulatively each second, therefore a condition statement was add to the software to consider the partial additive distances after stopping as equal to zero.

From the numerous experiments that had been made, it was observed that to record the shape of the curve in its true form, the bike speed and the observational rate should be least we can.

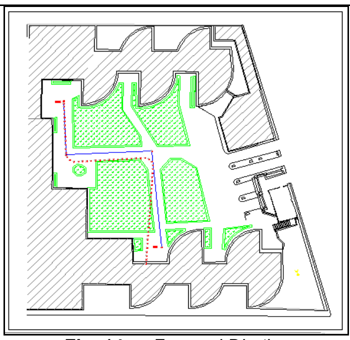

Fig. 14.a. *Forward Dirction*

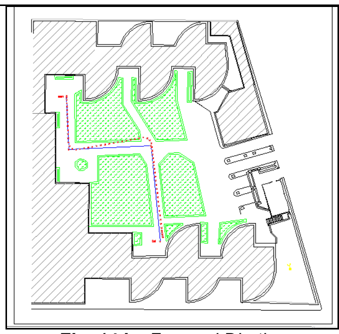

Fig. 14.b. *Forward Dirction*

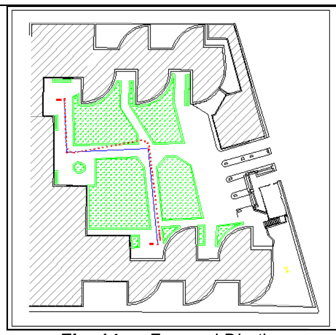

Fig. 14.c. *Forward Dirction*

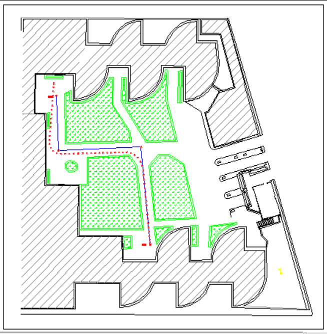

Fig. 14.d. *Backward direction*

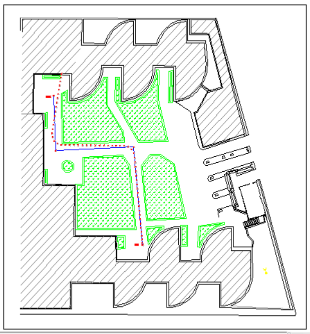

Fig. 14.e. *Backward direction*

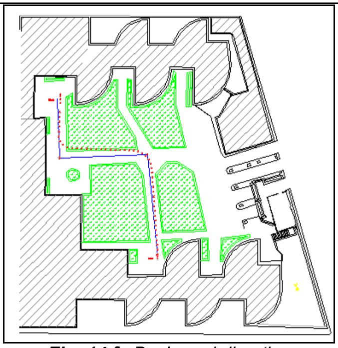

Fig. 14.f. *Backward direction*

Table 2. Difference between reference position and vehicle position

TEST No.	Ref. East (m)	Ref. North (m)	Veh. East (m)	Veh. North (m)	ΔE (m)	ΔN (m)	C.E. by length $\sqrt{\Delta E^2+\Delta N^2}$	C.E. by ratio = C.E /Total L
Start Point(forward)	0	0	0	0	0	0		
Test 1	-24.524	41.968	-25.061	41.258	0.537	0.71	0.89	1/73.0
Test 2	-24.524	41.968	-23.431	42.028	-1.093	-0.06	1.09	1/59.4
Test3	-24.524	41.968	-24.874	41.178	0.35	0.79	0.86	1/75.2
Start Point(backward)	0	0	0	0	0	0		
Test 1	-22.122	43.282	-22.862	43.379	0.74	-0.097	0.75	1/87.1
Test 2	-22.122	43.282	-23.182	43.032	1.06	0.25	1.08	1/59.7
Test 3	-22.122	43.282	-21.097	43.532	-1.025	-0.25	1.05	1/61.6

Table 3. Statistical data for accuracy of bike position

Direction	Min.(m)	Max.(m)	Mean(m)	±St.dev.
Local Easting	0.35	-1.09	0.094	0.924
Local Northing	-0.06	0.79	0.223	0.439

5.2.5. Assessment step in the second area.

To check the results, two additional experiments of longer paths in closed loop in the second area were made. The first one was nearly 200 m length, figure (15), while the second loop had length of nearly 800 m, both of two experiments started by local coordinates (E=0, N=0), figure (16). The obtained results of the two experiments are shown in table (4).

Table 4. Statistical data for accuracy of vehicle position

TEST	C.E. (East)	C.E. (North)	Closing error in length $\sqrt{\Delta E^2+\Delta N^2}$	Closing error in length. = C.E /Total L
Path L.200m	-2.381	0.623	2.46	1/81.3
Path L.800m	4.79	-8.403	9.67	1/82.7

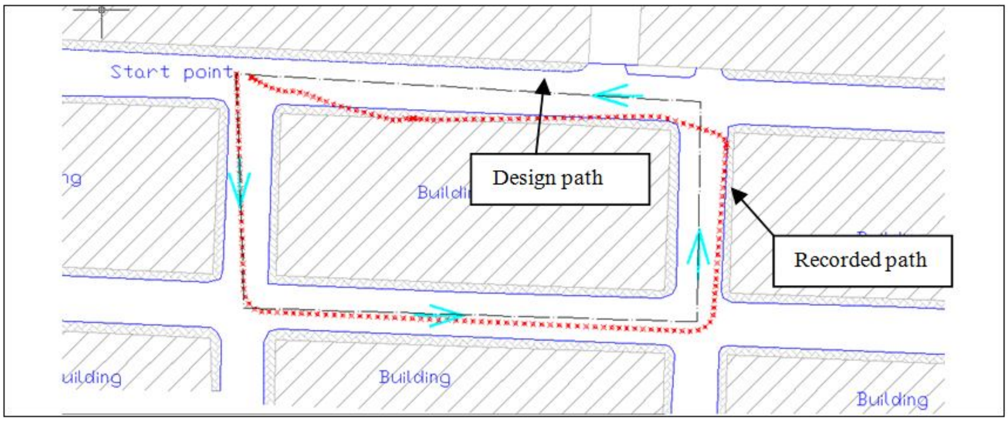

Fig. 15. *Study area2-out side Faculty of engineering –Soubra ˷ (Path length 200m)*

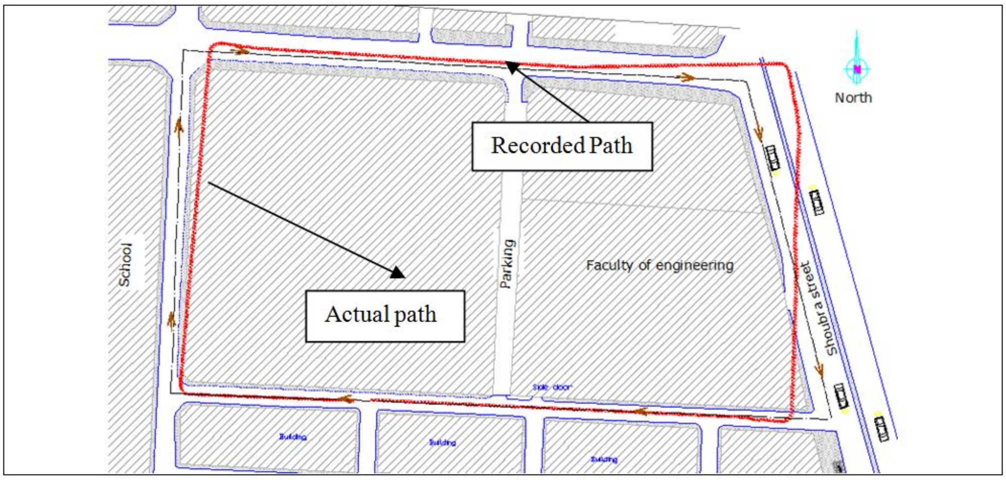

Fig. 16. *Study area 2-out side Soubra Faculty of engineering ˷ (Path length 800m)*

6. RESULTS AND ANALYSIS

- This paper presents a proposed low cost navigation system based on dead reckoning tools (Rotary Shaft Encoder), attached with a simple designed program by LABVIEW software.
- Figures (13) explain the preliminary experiments, and the proposed navigation system before any treatment of the collected data, where the recorded path was completely out of range. It is clear that the second set presented in figure (14) of the recorded paths after treatment, were almost compatible with the original designed path, due to the correct treatment of the system, mentioned in section (5.2.4).
- The most important steps of the system treatment that had a clear impact in improving and enhancing the accuracy of the recorded path were as follows:
  * * Select a lower sensitive encoder to observe the directions.
  ** To overcome the effect of any steering vibration of the bike, an if statement were added to the software to filter out every second, any difference in encoder's direction readings, within range ± 4º, and record it instead as equal zero.
- Table (4), Shows the relative accuracy of the proposed system through two experiments, which reach about 1/80 in both experiments, may be considered as an acceptable value for such a prototype system.

7. CONCLUSIONS AND RECOMMENDATIONS

The recorded data are collected and processed in real time. The data is collected on DAQ (NI USB-622x M Series) and the results were shown on the front panel screen, using conventional Laptop, from the those results we may conclude the following:

- The shaft encoder sensors could be exploited and used as a tool of a navigation system, starting from a known point and a known direction.
- The proposed system have many advantages such as; simplicity of its creation, low power consumptions for the DAQ operation, light weight, low coast and position calculations are made in real time.

Furthermore the hardware of this system is compatible with any Rotary Shaft Encoder sensors of different pulses, especially for distance measurements.

- The used software had added a great advantage to the system, by recording data and computing positions automatically in real time, through defining observational and computational time each second.
- The accuracy obtained from this system was limited, however, can be considered a natural consequence of a prototype model. Further investigation may be needed in future to enhance this system and to raise its accuracy.
- The suggested filtering for sensor's direction was very useful in reducing erroneous effect of the sensor's vibration due to the non smoothness of the motion surface.
- The speed of vehicle and observational time rate were two important factors affecting the collected data, low speed movement of the system was usually useful especially in a curved path, where the least measurable time interval (i.e. one second) was the best observational time interval, in other words, for recording the shape of the curve in its true form, the bike speed and the observational rate should be least.
- This system could be used as a standalone system in short distances and / or for many applications that need limited accuracy. It also could be integrated with GPS system to overcome its outages signal for any reason.

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