British Journal of Applied Science & Technology
10(4): 1-14, 2015, Article no.BJAST.18607
ISSN: 2231-0843

SCIENCEDOMAIN *international*
www.sciencedomain.org

SCIENCEDOMAIN

Hardware Efficient Scheme for Indoor Environment Using Grid Mapping

M. C. Chinnaiah[1*], T. Satya Savithri[2] and P. Rajesh Kumar[3]

[1]Department of ECE, BVRIT, Narsapur, Telangana, India.
[2]Department of ECE, JNTUCE, JNTU Hyderabad, Telangana, India.
[3]Department of ECE, PVPSIT, Vijayawada, Andhra Pradesh, India.

Authors' contributions

This work was carried out in collaboration between all authors. Authors MCC and TSS designed the study, the hardware developments are contributed by authors MCC and PRK. Experimental validations are performed by the authors MCC, TSS and PRK authors. Wrote the first draft of the manuscript and managed literature searches. Authors MCC, TSS and PRK managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2015/18607
Editor(s):
(1) Chien-Jen Wang, Department of Electrical Engineering, National University of Tainan, Tainan, Taiwan.
Reviewers:
(1) Anonymous, India.
(2) Anonymous, University of Guanajuato, Mexico.
(3) Stepan Bilan, State Economy and Technology University of Transport, Kiev, Ukraine.
Complete Peer review History: http://sciencedomain.org/review-history/10042

Original Research Article

Received 30th April 2015
Accepted 22nd June 2015
Published 6th July 2015

ABSTRACT

This paper addresses the mobile robot navigation using grid mapping. The proposal is to introduce dedicated Hardware scheme for robot navigation and it is deployed on Spartan 3E FPGA. The environment is divided into the grids, where landmarks are considered as grid points. Landmarks are RFID tags, among RFID system the reader is placed on the robot and interfaced with FPGA using UART protocol. The proposed path planning is also developed with obstacle avoidance mechanism to overcome the obstacles in robust environment. The robot navigation efficacy improves with the landmarks and hardware scheme. The hardware scheme is developed with NI lab view. Simulation and experimental results are furnished for proposed navigation algorithm in our laboratory.

Aim: Navigation of FPGA based Autonomous robot efficiently towards the target using grid mapping technique.

**Corresponding author: E-mail: chinna.chinnaiah@gmail.com;*

Study Design: The study of path planning methods. Among that efficient path planning is proposed with landmark by using grid mapping. Developed the hardware scheme for proposed algorithm.
Place and Duration of Study: Padamasri Dr B V Raju Institute of Technology, Narasapur, Medak (Dist), Telangana, 502313. Duration of study in 2014-15.
Methodology: Hardware scheme for autonomous robot navigation.
Results: Simulation results of proposed algorithm and experimental results with snapshots.
Conclusion: Navigation of Autonomous fpga based robot with a hardware scheme by parallel processing and using grid mapping methods.

Keywords: Path planning; hardware; landmark; obstacle avoidance; FPGA.

1. INTRODUCTION

Robotics is one of the most important fields in automation sciences, where assistance is improved in different areas of mankind like health, agriculture, transportation, service industries and so on. The mobile robots play vital role in automation and also in providing services. The researchers have proposed different navigation methods or algorithms for the mobile robots in both indoor and outdoor environments for last three decades. The importance of navigation with minimal sensing has increased in present scenarios. The mostly known path planning algorithms are as like D*, A* algorithms are used for navigation of robots.

Many algorithms have come into existence for computing the shortest path which has some merits and demerits. Palatino's graph growth algorithm implemented with two queues (TWO-Q) algorithm which is useful for path routing on road networks. This algorithm spends a lot of time on useless work when the shortest path is relatively short. An improved version of TWO-Q is Mild-TWO-Q algorithm which reduces the time to reach the shortest path [1].

Though conventional quad tree-based path planning approach is simple, robust and efficient has some limitations. Dijkstra's shortest path searching algorithm, a fast path planning overcomes the limitations of the quad tree by optimization of a path graph for both efficiency and accuracy is proposed in [2].

In real time applications, path planning in known or unknown environments is a difficult job. The D* algorithm is implemented for path planning in partially known environments with the help of sensor information. For effective path planning, improved version of D* algorithm based grids is studied in [3]. The path planning is also incorporated with the voronoio (GVD) [4] and visibility graphs [5,6]. Thomas M Howard et al. [6] was mentioned the developments of robot motion and planning in all terrains by preferring the graphical methods.

RFID-assisted indoor localization and the impact of interference on its performance [7]. Performance-based evaluation of RFID-based indoor location sensing solutions for the built environment is studied in [8]. Improving location awareness in indoor spaces using RFID technology [9]. Das A et al. [10] rely on the mapping to explore the unknown environment.

To find out the appropriate shortest paths in a convex polygonal environment, by reducing the visibility graph a new parallel algorithm is developed and its FPGA implementation is studied in [5]. Several practical applications that require high-speed shortest-path computations are developed by field programmable gate array (FPGA)-based accelerator to achieve high performance at low cost. Bellman-Ford algorithm adapted to solving the single-source shortest-path problem in a fast and efficient manner [11]. The proposed algorithm is carried out on FPGA (Spartan 3E) due to its high features like less power consumption and parallel processing nature [12]. The authors [13] are mentioned the shortest path planning algorithm upto the simulation results. In similar lines Abdelmoula C et al. [14] are explained the importance of FPGA's in shortest path planning using Altera's devices.

Navigation of mobile robots also developed by using the fuzzy and Neuro controlling methods. Algabri et al. [15] was described about the mobile robot navigation in an unknown environment with fuzzy logic approaches. Authors [15] are concluded as genetic fuzzy is best for travelling time and average speed. PSO-fuzzy and Neuron –fuzzy are efficient in distance travelled. Baturone I et al. [16] proposed about the robot navigation with Neuro-fuzzy using FPGA embedded controller, but it is limited to obstacle avoidance precision.

Obstacle avoidance mechanism is another key aspect in the navigation of mobile robots. In the early 1990's Lumelsky et al. are mentioned about the bug algorithms [17]. All these individual mobile robot algorithms can develop in PSO (practical swarm optimization). Supakar N et al. [18] has been developed the Obstacle avoidance for PSO's.

Presently, services for humans are provided by the robots, but all these robots prefers the path planning based on the particular identity like track. Track type of path planning has its own limitations like less self intelligence which fails to extend their services in all directions of the indoor environment. The Landmark determination method overcomes the track issues by proposing algorithm in service robots, by estimating its current position and improves self intelligence. When the robot is assigned to a desired task, it establishes a relevant path from the source to the destination with landmarks in the mapping environment. Path planning without track can increase the abilities of robot with minimum resources and fulfils the task in short span of time. The proposed path planning is also developed with obstacle avoidance mechanism to overcome the obstacles in robust environment.

1.1 Background

Dutch computer scientist Edsger Dijkstra proposed Dijkstra's algorithm in 1956 and published in 1959, [19,20] it is a graph search algorithm that solves the single source shortest path tree. This algorithm is often used in robot path planning to accomplish the task. The simple mathematical modelling preferred, weighted graph G= {E, V} and source vertex $v \in V$, such that all edge weights are nonnegative. The findings of Dijkstra's algorithm shortest paths (or the shortest paths themselves) from a given source vertex $v \in V$ to all other vertices. This algorithm hardware scheme proposed by the authors [6], but not mentioned real time node point with any device or component. In this context, this research work developed a new VLSI-efficient scheme with landmarks for real time scenarios.

This research work summarizes in different sections like Section 1 introduces the introduction of robotics path planning and also the importance of landmark determination. Section 2 presents the proposed algorithm with necessary environments and environments. Section 3 gives VLSI architectures for proposed algorithm with the explanation of individual blocks. Section 4 deals with experimental setup and results. Section 5 concludes with conclusions and future scope.

2. PROPOSED PATH PLANNING ALGORITHM

The interest of authors is to develop assistive methods to reduce the human efforts by using robots in service oriented indoor environments. The main theme of this chapter is to develop an autonomous FPGA based robot of self intelligence which can assist in the service environment to perform various tasks by sensing its location with the help of Landmark (RFID) tags. The environment is mapped initially with defined parameters like distances between one location to another location. When a robot receives a task by the external world, it assesses all the possible probabilities for different paths to reach indeed destination. Among all probabilities it looks attentively at the low weight, distance path as the shortest route by comparing the distances from present location to the desired task destination using FPGA hardware.

The obstacle detection and obstacle avoidance is one of the major issues to reach the destination successfully. It can easily detect all the obstacles through ultrasonic sensors and avoids by obstacle mechanism which is developed in FPGA control unit. The mobile robot equipped with eight ultrasonic sensors and RFID reader is configured to the robot such that it can be capable of estimating particular location and move towards the destination. With the help of these devices (ultrasonic sensor and RFID) which are of being low cost, the robot can easily accomplish any kind of navigation task.

An RFID system is a pair of RFID Reader and RFID Tag. A radio frequency identification reader (RFID reader) is a device used to collect information from an RFID tag. All RFID tags are unlike to each other and contains the unique ID about a particular location.

RFID system works under the phenomenon of electromagnetic. RFID reader has an antenna and creates a electromagnetic field in its surrounding areas. When the robot moves close to the RFID tag, the tag gets activated by the emission of electromagnetic field emitted by an

RFID reader. The RFID reader reads the tag's unique value which is under the electromagnetic field and stores in stack memory. It gathers all the tag data sequentially in the given environment and stores in a stack memory. After receiving all the available tags it evaluates its current position and take appropriate action to reach the next step. In this manner, it moves step by step based on the collected data.

Ultrasonic sensors are used to detect the obstacles and avoid the obstacles by easy method of distance measurement (PWM). The sensor continually transmits an ultrasonic wave. When the ultrasonic wave hits the obstacle, it gets reflected to the sensor as echo signal. By measuring the echo pulse width, the distance of the obstacle can be easily calculated. By knowing the distance value the robot changes its direction with the help of stepper motors into the path where there are no obstacles. Finally, it traverses the path towards the destination.

2.1 Indoor Environment

The indoor environment is represented in Fig. 1, it consists of six different Halls like Hall A, Hall B and so on Hall F. Respective RFID tags are placed at each hall. The current position of the robot is identified by using RFID tags. One of the experimental exemplar is followed by considering the desired task as Hall 'F', when the robot is localized at Hall 'A'.

The weights of the path distance of different path probabilities between starting Hall 'A' to destination Hall 'F' are evaluated. The comparison circuit between path distances concludes the shortest path. The same path is defined as the trajectory of the robot, in this example shortest path is A-D-E-F. All these computations are done in control unit of the FPGA.

Robot continually checks for RFID tag values, then moves towards the destination with respect to the path planning algorithm. The each Hall is having subset Landmarks for example Hall A by A1, A2, A3 in the localization of the robot. This subset values is used for accurate path planning by the correction and prediction module.

2.2 Pseudo Code for the Proposed Algorithm

Algorithm Steps:

Step 1: The Localization of the robot is performed by capturing the landmark by RFID system.

Step 2: The next level of algorithm is assigned by desired task. The Probability Path Analyzer module gives the shortest path between source to destination node as shown in Fig. 2.

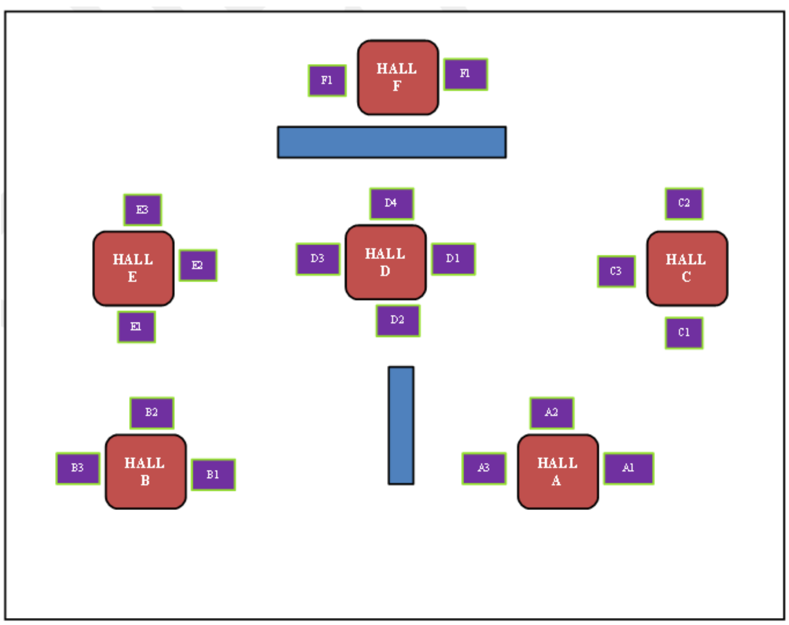

Fig. 1. Illustration of indoor environmet

Step 3: The robot starts at source point and traverse towards the destination point by using the RFID landmark. Each Hall has few subset landmarks, it provides perfect direction to traverse towards indeed destination.

Step 4: In trajectory of the robot, it also visits the other Halls to reach the final destination node. In this process the correct module internally having computation method which always checks the visited Hall and gives the next Hall of the trajectory to achieve proper path planning. The path traversing has shown with flow chart in Fig. 3.

Step 5: when the robot reaches for final Hall, it compares with destination Hall and concludes as a goal.

Remark 1: After evaluation of different path probabilities at step 2, one of the examples Hall 'A' considered as start and Hall 'F' as the destination. The shortest trajectory of the robot between A to F presents as A- D -E – F path as shown in Fig. 2.

Remark 2: According to the example the robot start from 'A' and feed forward up to 'D' landmark. If any subset of 'D' landmark is achieved, it considered as D and corrects the next direction of the path as shown in Fig 3. This action performed by correction and verification module. It repeats similar method for all Halls.

3. VLSI ARCHITECTURE OF PROPOSED ALGORITHM

The Proposed algorithm architecture is deployed on FPGA and navigated successfully. The sensor modules are used to estimate the distance with pulse width modulation technique. Minimum distance finder exhibits output for each sensor. The angles are known in path planning by digital compass module with UART protocol. The CORDIC IP core module has been used for trigonometric computations The soft core odometer module is a special technique developed for computing odometer distance without external devices. The CU also bridges the communication between the FPGA and external devices like sensor and compass. It performs parallel processing in sensing the information, odometer and angle computations and, other than these, the motors are driven by motor logic control, the actions required are synchronized with device clock frequency.

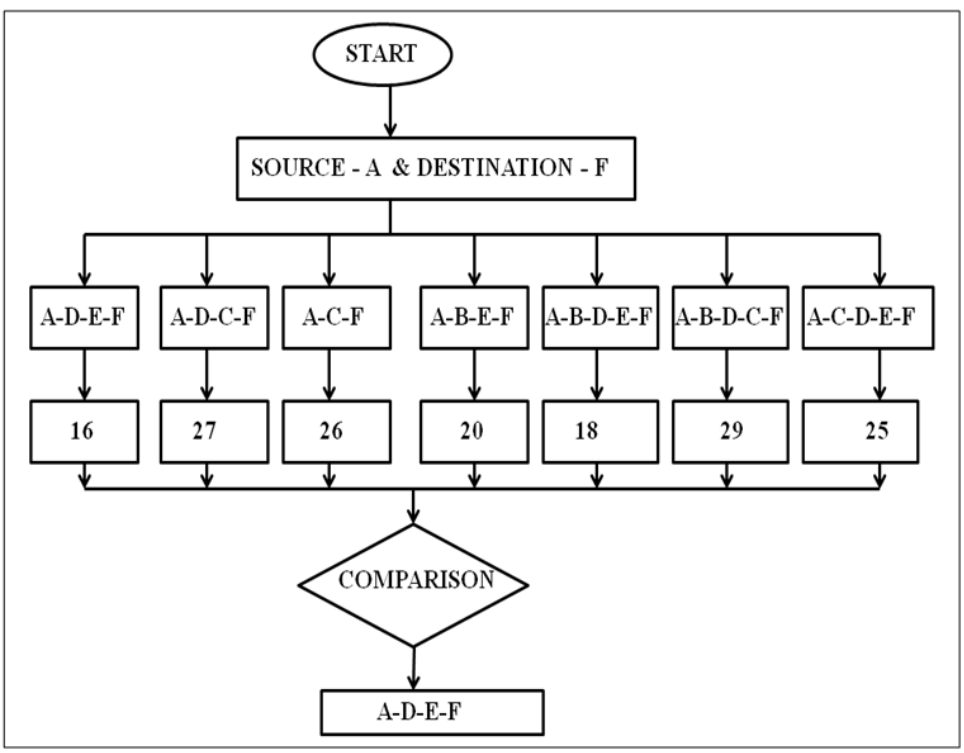

Fig. 2. Flowchart for identification of shortest path

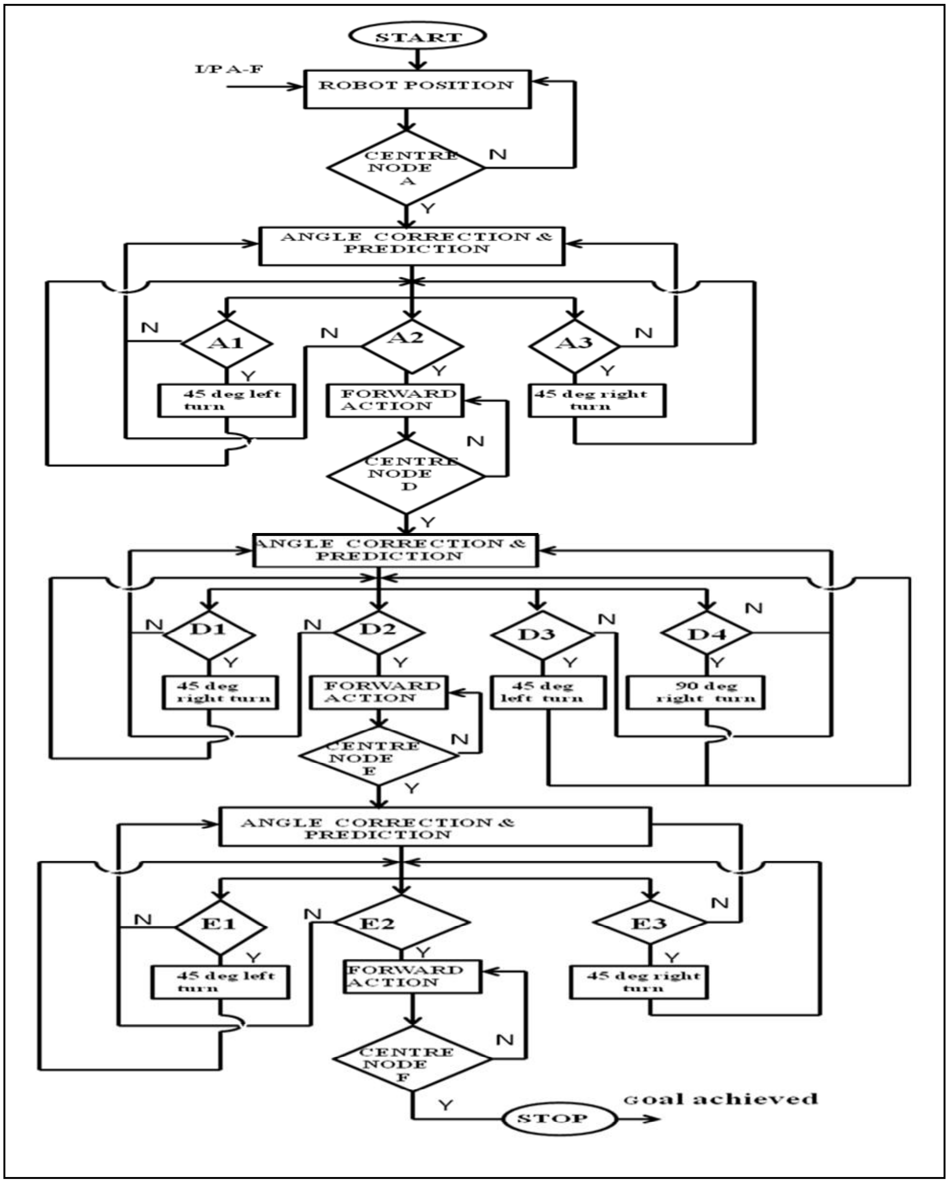

Fig. 3. ASM chart for path navigation

3.1 FPGA (Control Unit)

Here the control unit is Xilinx board XC3S2000 (FPGA Spartan 3E). In this research FPGAs are preferred due to its parallel processing nature. The control unit controls all the devices and navigates the robot to reach the destination. The architecture is developed by the behavioural modelling. The Xilinx CORDIC soft core is incorporated for angle evaluation and computations. Control unit was integrated with the following modules internally like 1) Initialization and Destination Module 2) Path Probabilites Module 3) Robot Navigation Module.

3.1.1 Initialization and destination module

This module comprises of very first job whenever a task is given to the robot. This module particularly helps to know its initial position, with the help of RFIDs. Initially the robot gets a two tag values which indicate a source and destination. Among them it considers first Tag value as source point and second as destination point. All the tag values which are under given environment are stored in a stack memory. When robot receives two tag values it is compared to the tag values which are already in the stored in the memory and comes to the conclusion with a particular Halls as a source and destination.

3.1.2 Path probabilities module

This module is followed by initialization and the destination. By receiving the source and destination, it checks for all probabilities and chooses a feasible path which is of low weight age using comparator circuit.

3.1.3 Robot path navigation

This module comprises of correction circuit. From the above module it gets the shortest path to navigate towards the destination. Correction circuit helps the robot to choose appropriate subsets by taking required angle and enters into next Hall.

3.2 Matching Circuit

The matching circuit comprises of the comparator and FIFO. The signals from the ultrasonic sensors are converted into pulses. With these pulses the distance of an object can be obtained. Now, the obtained distance value is compared with matching circuit whether to focus the obstacle or to discard the obstacle. Similarly, all the RFID Tag values are stored in the FIFO and gives the appropriate signals to the control unit to perform the required action.

3.3 Uart Module

The UART is a serial communication protocol used to interface RFID to the robot. The 12 byte data on RFID Tags are transmitted to control unit through the UART protocol.

3.4 Motor Controller Module

Depending on RFID & Ultrasonic inputs, the control unit produces specified signals to motor controller module. Which helps the robot to move in all required directions like left action, right action etc.

4. EXPERIMENTAL SETUP & RESULTS

4.1 Experimental Setup

The Fig. 5 shows the experimental setup or architecture of prototype to perform the given task. The heart of this setup is an FPGA (SPARTAN 3E), it fetches signals from the ultrasonic sensors and RFIDs for navigation of robot. Control unit (FPGA) drives the stepper motors through the driving circuits. The Power supply equipped with 12 v and 3000 mah. The voltage regulator is on-board available to power up the sensors.

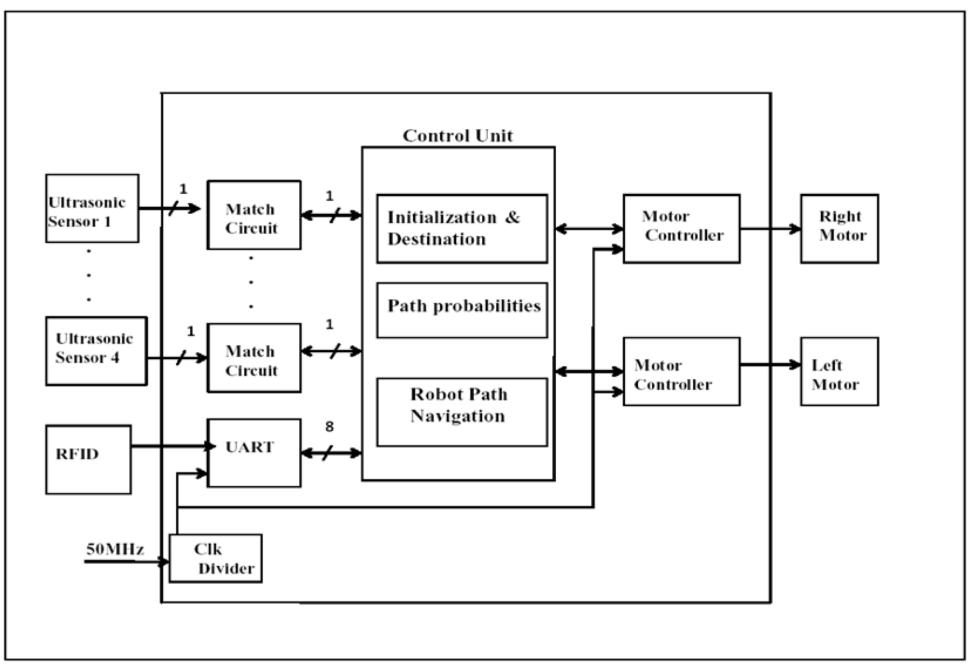

Fig. 4. Overall VLSI architecture of proposed algorithm in indoor environments

4.2 Simulation Results

4.2.1 Initialization module

The below simulation results illustrates the initial position of a robot. In the given indoor environment in Fig. 6 there are seven different halls like HALL _A to HALL _F with their respective sub nodes. In Fig. 6 A, B, C, D, E and F are parent nodes and the notation for these halls are given in binary as 001,010,011,100,101,110 respectively. A1, A2, A3, B1, B2……F1, F2 are sub nodes having different RFID Tag values.

When RFID Reader reads the sub node values, Robot concludes its corresponding parent node as initial position. For e.g., if Robot reads any one of 51 or 52 or 53 it identifies A-001 as its initial position. In the above simulation robot reads the 54 tag values in between 200 ms and 400 ms and concludes B as initial position.

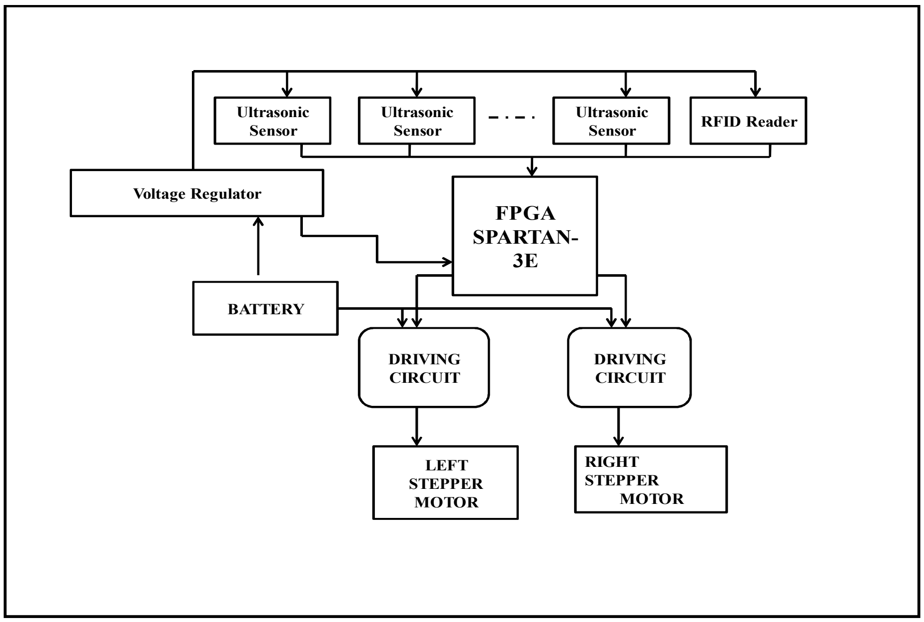

Fig. 5. Block diagram of robot with FPGA

Fig. 6. Simulation results of initialization module

4.2.2 Destination module

In the below waveform (Fig. 7), robot evaluates the destination from external source. Here Hall A, Hall B….. Hall F is the different Halls in a given environment, having different number of RFID tags. When an RFID reader reads the data from the RFID tags the control unit checks the data is from which node and gives the appropriate Hall as a destination.

In the below simulation (Fig. 7), robot gets destination node from Zigbee module. Here, at 0-200 ms the Zigbee data is 51. Since 51 is a sub node of A and A is treated as destination point. Similarly, at 600 ms the Zigbee data is 68. Since 68 is a sub node of F and F is treated as destination point.

4.2.3 Path probabilities

In the above waveform (Fig. 8), the robot checks all the path probabilities for giving initial and destination locations. Among all the path probabilities, robot compares for the shortest path and navigates through that path.

In the above simulation (Fig. 8), initial and destination nodes are given by RFID and Zigbee modules. Here when the robot gets an input as (A and F), (B and F)…. so on. For every input there will be a number of different paths having different weight ages. Among those paths robots uses the comparison module between all paths and gets the shortest path as a desired path. Here the above simulation gives required paths for different inputs.

4.2.4 Robot path navigation

The below simulation (Fig. 9) gives the Robot navigation after getting initial and destination nodes. This simulation shows how the robot navigates towards destination for the input (A and F). From the path probability simulation robot gets desired path as A-D-E-F. Here at the time period 100 ms when it reads 51tag it enters into the A (001) node. At 200 ms it reads the 60th tag and enters into D node. Similarly, it enters into E and F when it reads them sub nodes respectively.

Table 1. Parent and the child node's RFID values

Source location (Parent, Node)	A – 001	B - 010	C - 011	D - 100	E – 101	F - 110
RFID TAGS	A1 -51	B1 -54	C1 -57	D1 -60	E1 -64	
(Sub nodes)	A2 -52	B2 -55	C2 -58	D2 -61	E2 -65	F1 -67
	A3 -53	B3 -56	C3 -59	D3 -62	E3 -66	F2 -68
				D4 - 63		

Fig. 7. Simulation results of destination module

Table 2. Probabilities of shortest path planning

Initial and destination	A – 001 & F - 110	B – 010 & F - 110	C – 011 & F - 110	D – 100 & F - 110
Path	A-D-E-F	B-D-E-F	C-D-E-F	D-E-F

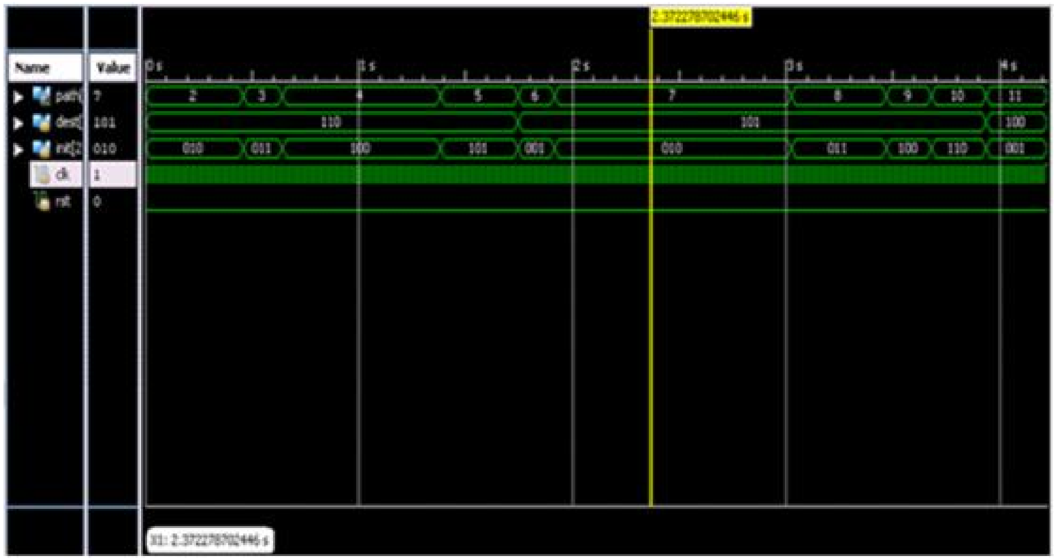

Fig. 8. Simulation results of path probability module

Fig. 9. Simulation results of navigation module

<u>4.2.5 Obstacle avoidance</u>

In the below waveform (Fig. 10), robot overcomes the obstacle and continues travelling on the desired shortest path. Here robot gets an obstacle between the subsets A&D, It avoids the obstacle and moves in through D, E & F nodes. This simulation shows how the robot avoids the obstacle in its desired path. In the figure. The robot gets an obstacle between the nodes A and D. Here at the time period 120 ms (S1=1 i.e. it indicates obstcale) and performs obstacle avoidance and enters into D node at 170ms.

4.3 Synthesis Report

Fig. 11 represents area consumption, it relied on the table 3 Xilinx FPGA board Spartan XC3S2000. The basic units of the area have depended on CLB's occupied with LUT's.

4.4 Experimental Results

Fig. 12a- h are represented proposed hardware based robot navigation with grid mapping as mentioned in the section 2. The Fig. 12a is localization of the robot and remaining snapshots represents the navigation of the robot from the A grid point to the F grid point (intended destination).

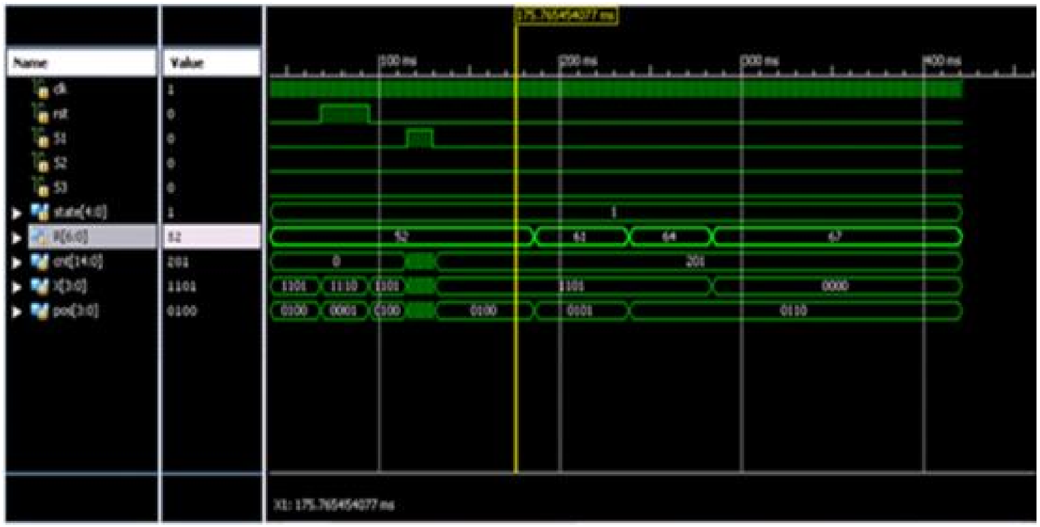

Fig. 10. Simulation results of obstacle module

Table 3. Area consumption on Xilinx FPGA board Spartan XC3S2000

Block	No. of slices	No. of 4 i/p LUTS
Matching Circuit	84	176
Control Unit	652	1304
US Sensor Module	67	114
UART module	293	584
Motor Logic Control	86	166
Obstacle avoidance module	184	264
Total	1366	2608 (5.6%)

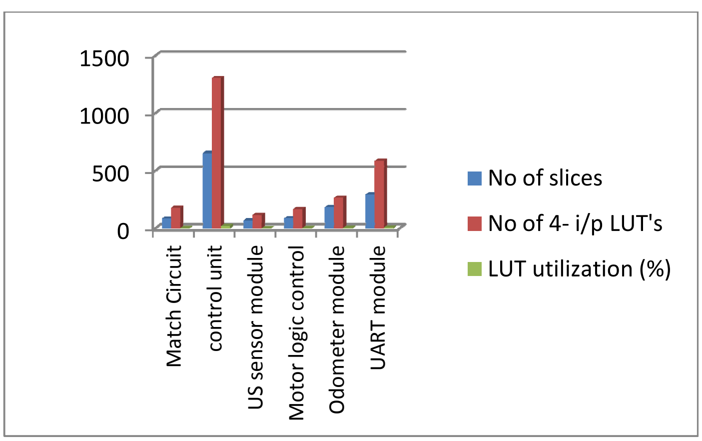

Fig. 11. Analysis of area consumption on FPGA board

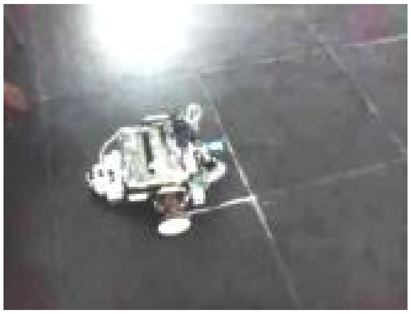

Fig. 12a

Fig. 12b

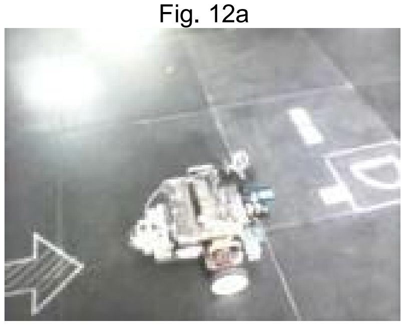

Fig. 12c

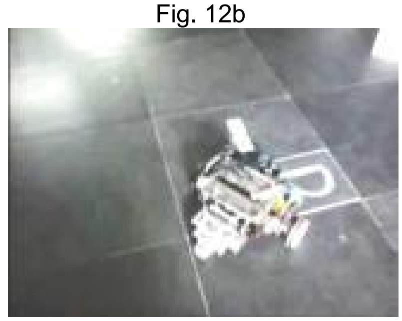

Fig. 12d

Fig. 12e

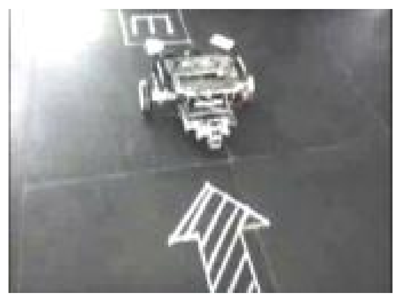

Fig. 12f

Fig. 12g

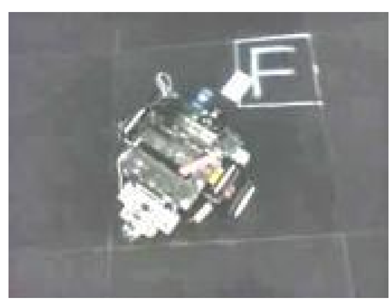

Fig. 12h

Figs. 12a-12h. Snapshots of Proposed algorithm's experiment results

4.5 Comparison Results

The other robot path planning algorithms like D*, A* is not perfectly fitted towards service environment. Hardware based D* algorithm shortest path planning [8] is limited to the navigation computations. The novelty of proposed algorithm is perfectly drive the robot path by landmark determination and comparatively [9] it best up to our knowledge. The proposed algorithm mainly depended on landmarks (visited nodes). Precision navigation can be done by using the Landmark or grid mapping.

Table 4. Area consumption on Xilinx FPGA board Spartan XC3S2000 by visiting node

RFID's in the environment (nodes)	BRAM
16 visited nodes	18 (45 %)
24 visited nodes	27 (67.5%)

In comparison with [9] (for 64 nodes occupied the 124 BRAM), the proposed algorithm occupies 72 BRAM (for 64 nodes) in an FPGA device. The other papers [16] used Fuzzy controller and Micro blaze it occupies more device space. The efficiency is improved in driving the path by the hardware scheme (FPGA), it made parallel processing with low power consumption [21]. We preferred the Lower FPGA device (Spartan 3e 2000) than vertex II [16].

5. CONCLUSIONS

This Paper presents path planning in service robot in a robust environment. In Taiwan and Japan the restaurants are preferred to use the track system navigation to deliver the food. We developed the hardware efficient algorithm, it can be incorporated in industrial and service environments (hotel). In this research work, the usage of landmarks increased the abilities of a robot in knowing its current position and navigate to the intended goal point. Its precision is improved in navigation and device utilization than [6,13]. Its performance is validated by experiments in the defined environment have been done successfully in the laboratory. The FPGA energy consumption is only 9.64 Joules during obstacle avoidance and path planning for this experiment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. JinFu Leng, Wen Zeng. An improved shortest path algorithm for computing one-to-one shortest paths on road networks. Information Science and Engineering (ICISE), 1st International Conference. 2009;1979-1982.
2. Joe Young Hwang, Jun Song Kim, Sang Seok Lim, Kyu-Ho Park. A fast path planning by path graph optimization. Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions. 2003;33:121-129.
3. Jianming Guo, Liang Liu, Qing Liu, Yongyu Qu. An improvement of D* algorithm for mobile robot path planning in partial unknown environment. Intelligent Computation Technology and Automation, 2009. ICICTA '09. Second International Conference. 2009;394-397. DOI: 10.1109/ICICTA.2009.561.
4. Vachhani L, Sridharan K. Hardware-efficient prediction-correction-based generalized-voronoi-diagram construction and fpga implementation. Industrial Electronics, IEEE Transactions. 2008; 55(4):1558,1569.
5. Priya TK, Sridharan K. An efficient algorithm to construct reduced visibility graph and its FPGA implementation. VLSI Design, 2004. Proceedings. 17th International Conference. 2004;1057-1062.
6. Howard T, Pivtoraiko M, Knepper RA, Kelly A. Model-predictive motion planning: Several key developments for autonomous mobile robots. IEEE Robotics and Automation Magazine. 2014;21(1):64-73.
7. Chakravarthy N, Jizhong Xiao. FPGA-based control system for miniature robots. 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems. 2006;3399-3404.
8. Sridharan K, Priya TK, Kumar PR. Architecturally-efficient computation of shortest paths for a mobile robot. IEEE Symposium on Industrial Electronics & Applications. ISIEA 2009;277-282.
9. Sridharan K, Priya TK, Kumar PR, Hardware architecture for finding shortest paths. IEEE Region 10th Conference TENCON. 2009;1-5.
10. Das A, Diu M, Mathew N, Scharfenberger C, Servos J, Wong A, Zelek JS, Clausi DA, Waslander SL. Mapping, planning, and sample detection strategies for autonomous exploration. Journal of Field Robotics. 2014;31(1):75-106.
11. Jagadeesh GR, Srikanthan T, Lim CM. Field programmable gate array-based acceleration of shortest-path computation. Computers & Digital Techniques, IET. 2011;231-237.
12. Chinnaiah MC, Sanjay D, Kumar PR,Savithri TS. A Novel approach and Implementation of Robot path planning using Parallel processing algorithm, International Conference on

Communications. Devices and Intelligent Systems (CODIS). 2012;345-348.
13. Chinnaiah MC, Divyavani G, Satyasavithri T, Rajeshkumar P. Implementation of Shortest path planning algorithm without track using FPGA robot: A new approach. 2014 International Conference on Advances in Electrical Engineering, ICAEE 2014.
14. Abdelmoula C, Chaari F, Masmoudi M. Real time algorithm implemented in Altera's FPGA for a newly designed mobile robot: Autonomous navigation and parallel parking. Multidiscipline Modelling in Materials and Structures. 2014;10(1): 75-93. Art. No. 17112943.
15. Algabri M, Mathkour H, Ramdane H, Alsulaiman M. Comparative study of soft computing techniques for mobile robot navigation in an unknown environment. Computers in Human Behavior. 2015;50: 42-56.
16. Baturone I, Gersnoviez A, Barriga Á. Neuro-fuzzy techniques to optimize an FPGA embedded controller for robot navigation. 2014;21:95-106.
17. Lumelsky VJ, Mukhopadhyay S, Sun K. Dynamic path planning in sensor-based terrain acquisition. Robotics and Automation, IEEE Transactions. 1990;6(4):462-472.
18. Supakar N, Senthil A. PSO obstacle avoidance algorithm for robot in unknown environment. (2014) 2013 International Conference on Communication and Computer Vision, ICCCV 2013.
19. Dijkstra EW. A note on two problems in connexion with graphs. Numer. Math. 1, (1959);269–271.
20. Dijkstra EW, Misa TJ. (eds.): An interview with Edsger W. Dijkstra. Commun. ACM. 2010;53(8):41–47.
21. Yongguo Mei, Yung-Hsiang Lu, Hu YC, Lee CSG. A case study of mobile robot's energy consumption and conservation techniques. Advanced Robotics, ICAR '05. Proceedings. 12th International Conference. 2005;492-497.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/10042