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FPGA Based Wheelchair Autonavigation for People with Mobility Issues

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***Abstract*— About 65 million people out of 650 million with disabilities in the world require wheelchairs for mobility. Only a minority of them have access to electric wheelchairs in developing and underdeveloped nations. The count is even less when it comes to sophisticated wheelchairs. These electric wheelchairs come with joystick control which is not suitable for people with stroke and spinal cord injury. In this research work we propose a FPGA based solution for automatic navigation of electric wheelchairs in indoor navigation. The house floor is divided into virtual grids with specific co-ordinates assigned to each grid. As a predefined path is fed into the system to reach a destination from a source the system works faster compared to the specific path finding algorithms for path calculation. The Matlab implementation and the Verilog HDL implementation, analysis, synthesis are discussed detailed in this paper.**

Keywords—autonavigation, wheelchair, FPGA, mobility issues

I. INTRODUCTION

As per the studies done by WHO (World Health Organization) it is estimated that out of 650 million peoples with disabilities 10% of them need wheelchairs for their day to day locomotion. The noticeable factor is that in developing countries like India only a minority of them have access to an appropriate wheelchair. Autonomous power wheelchairs provide greater aid to high degree of physically challenged people. Rather than providing mobility, an appropriate wheelchair benefits the physical health and quality of life of the users and assists them to become productive members of their communities. But the financial condition of people with such disabilities makes them difficult in accessing appropriate wheelchairs.

Our proposed working model will free users from the burden of continuous physical effort needed for navigating powered wheelchairs and try to make it cost efficient. Most of the houses have lesser than 10 room on the ground floor. This floor is divided into virtual grids and a specific grid in each room is identified as source/destination. The paths from each source to destination, called fixed path, are stored in the internal memory. Depending on the number of rooms, a user control interface (voice, switch based etc.) in the wheelchair can be used to point to the destination the user wants to navigate to. The fixed path module is implemented using Matlab and is tested for various grid counts, sources and destinations. The entire FPGA based controller system is implemented and simulated using Verilog HDL, testing for various grid counts, sources and destinations. The design is synthesized using Xilinx CAD tool and the result is analyzed on the basis of memory usage and time consumption for the controller system.

II. RELATED WORKS

The automated powered wheelchair provides greater help to physically challenged people by providing a proper assistance to make their mobility easier. Most of the research work is on the control method used for continuous navigation in electric wheelchairs. Many experiments are done at different levels for the transition from mechanical or manual wheelchairs to powered wheelchairs. There are some research works in which researchers use micro-controller [12], and micro-processor based automated navigation systems. For path optimization there are lots of path finding algorithms are used commonly like the Depth-First Search, the Breadth-First Search, the A * algorithm, the Dijkstra's algorithm, the neural approach, and the genetic algorithms [2]. Here the researchers part the environment into 2D grids. Thus each grid represents a node and connection between any two grids (path taken by avoiding obstacles) becomes edge and then use the algorithms.

In interfacing media- the hand gesture recognition is a method, where MEMS accelerometer is used to detect the accelerations of hand in motion in three perpendicular directions and using Bluetooth wireless protocol to transmit these data [3] and control wheelchair motions. In case of head movement based navigation an accelerometer device is fixed on the forehead of the users [4] and controls the wheelchair motion in any of the four directions. Voice capture module is used to detect the voice of a person and compared with predefined voices loaded in system by voice recognition module [5]. In localization methods used in automated electric wheelchairs – RFID tags are used to cover the area of each grid [6]. The ceiling lights can also be used as landmarks since they can be easily detected due to the highly contrast between light and ceiling surface [7]. The dimension of grids depends on the area where light is installed. WLAN, infra red and UWB based wireless systems are used as positioning system in complex buildings [8].

In our work, we propose, not to use any of wireless based sensors or technology for localization, which would require some changes to the house environment like installing sensors/ access points etc. all over the house. We use digital compass for orientation data and rotation encoder for distance data. This way the cost of implementation is reduced. But the initial position of the wheelchair, i.e. the coordinates of the start grid has to be known to the system.

III. DESIGN AND IMPLEMENTATION

The system architecture is shown in Fig.1. The overall functioning starts from taking initial one time input which is a grid map of the indoor environment to navigate [10]. This map divides the entire 2D-floor plan of the house into small rectangular grids (whose grid dimension is determined from wheel radius) and this grid information is converted to a typical matrix, which is fed into the memory of the FPGA controller. As the house is a static object, the contour of the house is not going to change dynamically. So our initial input will be the address of grids which together makes paths of different source grid and destination grid.

Typically a house might have only 4 or 5 rooms in the ground floor. The floor is divided into grids and the static objects are identified and marked. The walls are considered to be static as well. A grid in each of the room is identified as source and destination. As we are proposing a predetermined fixed path, a source grid can act as destination as well. The wheelchair can move only in this fixed path and start or stop only in those grids identified as source or destination. This way there is no need of using path finding algorithms for path calculation which increases the computational complexity in terms of memory and time. The runtime usage of memory can be reduced and we can save the time taken for calculating the shortest path each time. As we know the static obstacles present inside the house, the paths between the identified sources and destinations are calculated in advance, stored separately in memory and use it when need arises. User specific grid is taken as reset grid, where we assume the initial location of wheel chair as this grid. We have to manually take wheelchair into this location and press the reset button. The system is now aware of current location or source location after which it is ready to navigate automatically to the given destinations. The destination information is given by the user through switches. Once the destination is identified the system will automatically guide the wheelchair to corresponding destination via stored path.

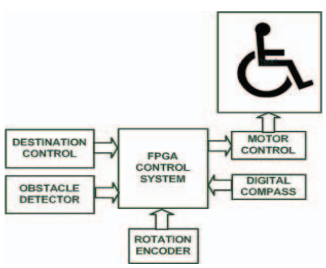


Fig. 1. System Architecture

Figure 1 shows the system architecture of the entire setup. The destination controller board processes the destination information input by the user through switches. Further it takes to the destination through the shortest path as predetermined and stored in the system. System's FPGA controller configures various sensors and interfaces with them for successfully taking the wheelchair to the destination. Digital compass is used for continuous direction monitoring and direction information is fed to the FPGA. HMC6352 digital compass will communicate with the FPGA controller through I2C protocol. Rotation encoder keeps track of the position of system in the indoor environment and the job of FPGA controller unit is to process the given path and generate corresponding control signals for the next block. Those control signals are then fed to motor control unit which is a set of motor drivers to control the speed and the direction of powered wheel motors to take it to the intended destination.

The FPGA controller block diagram is shown in figure 2. The one time grid plan stored in the memory, data obtained from destination controller module, digital compass and obstacle finder serve as input. Control signal needed for motor driver serves as output.

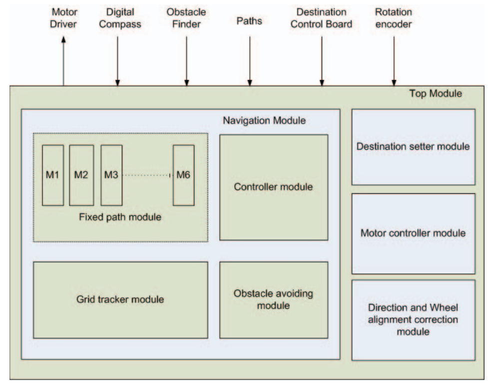


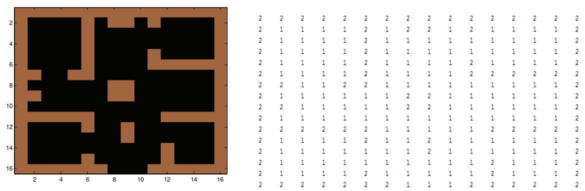
Fig. 2. Block diagram of FPGA controller

Navigation module is designed for dealing the navigation part of controller. And it is further divided as fixed path module which gives the corresponding path for given source grid and destination grid. Obstacle avoiding module calculates the grid position of the obstacle. The sonar sensor LV Max Sonar EZ 1 is capable of detecting objects up to 6.45 meters and is used as obstacle detector. Grid tracker module calculates the current grid position of the system. It gets information regarding the distance covered by the system and direction of movement. Controller module provides corresponding control signal to the three sub modules. The destination setter module takes the input from destination control board and gives destination grid as its output. Motor controller module gives instruction to motor controller IC required for navigation. The request from direction and wheel alignment module has higher priority than navigation module so that system can avoid path deviation due to error in wheel alignment. Direction and wheel alignment correction module is designed for finding direction of movement and correct the wheel alignment.

As there is no algorithmic time involved to calculate the path. the computational complexity for this case is taken as zero. It is like feeding the predetermined path with fixed source/destinations to the wheelchair. There is no algorithm engaged to calculate the path. If there are N number of source/destinations, then the user has to feed [N x (N-1)]/2 fixed paths into the simulator for the wheelchair to navigate. If N = 5, then the number of fixed paths would be 10. Where are if any of the path finding algorithms are going to be employed then the computational complexity is going to be the O(X) where X can be an integer or square of an integer or a logarithmic function etc.

IV. Testing And Evaluation

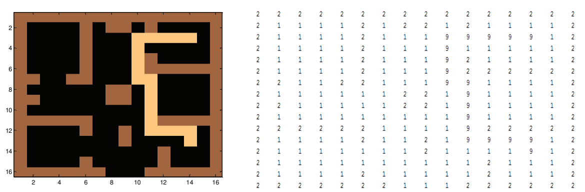
Initially the fixed path module is implemented using MATLAB and was tested for different grid sizes. The Fig. 3(a) represents a visual representation of sampler floor plan of house. The light brown color shows the wall of house or static obstacle such as dining table, chair, bed etc. The black colored region indicates one or more grids where the wheelchair can traverse freely.



(a) (b)

Fig. 3. (a) Sample floor plan (b) Matrix representation of sample floor plan

Fig. 3(b) shows the matrix representation of the above floor plan, where the number 2 indicates the walls and static obstacles and 1 indicates the free grid. The grid dimension taken is 16x16, where each grid of size assumed to be 1mx1m. The Fig. 5 gives visual representation of a path with source grid (46) and destination grid (206) in which the cream color shows the path traversed. The Fig. 4(b) shows the matrix representation of floor plan shown in Fig 4(a). Here number 9 represents the path traversed by wheelchair.



(a) (b)

Fig. 4. (a) Visual representation of path obtained. (b) matrix representation of path obtained

FPGA controller is implemented using Verilog HDL, simulated in Modelsim and synthesised using Xilinx 12.1 synthesis tool for a sample plan and tested for different test cases. Here rather than matrix we represents the 2D grid plan with X,Y coordinates. As an example a 16x16 sample floor plan as shown in Fig. 7 (a) is considered. As per the plan, there are four rooms and the source and destination of each room is predetermined and shown as blue grids. Here the red grids show walls and static obstacles, grids with white color show free grids. Both the decimal and hexadecimal values of each of the grid is shown in the figure. Consider a path from source grid [2d] to destination grid [cd].

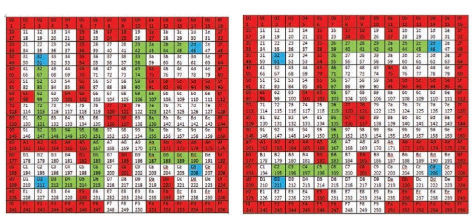
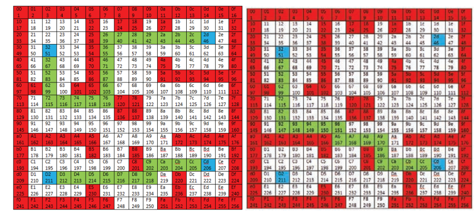


Fig. 5. (a) A sample floor plan that showing paths from grid[d2] to grid [32] and from grid [cd] to grid [2d]. (b) A sample floor plan that showing path from grid [2d] to grid [d2].

The green color grids show the path to be traversed by wheelchair as predetermined by the user. The figures 5(a), 5(b), 6(a), and 6(b) show the predetermined fixed path possible between the four rooms in the given house contour. In this sample floor plan total 4 rooms are there indicated by grids [2d],[cd],[d2] and [32]. There will be 12(4x3) paths possible connecting these destinations including to and fro.



(a) (b)

Fig. 6. (a) A sample floor plan that showing paths from grid[d2] to grid [cd] and from grid [32] to grid [2d]. (b) A sample floor plan that showing paths from grid[32] to grid [cd]

The waveform generated in ModelSim is given in Fig. 7. A grid plan of 16x16 dimensions is taken as sample and the grids 2d, cd, d2, 32 are taken as destination grids which represents rooms in a house. There are 12 path exist connecting these 4 destination points. But in actual case it can be divided in to 6 paths if we consider to and fro paths as one.

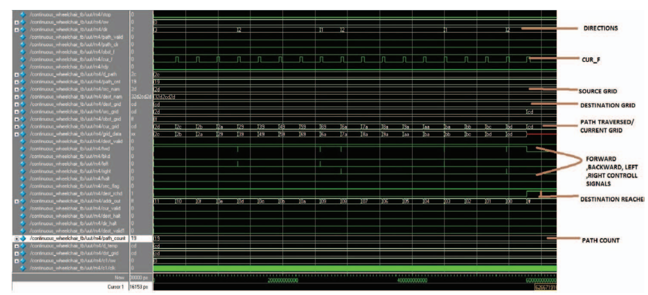


Fig. 7. wave form obtained after simulation in Modesim.

Since we already know the contour of house we can manually find the paths and store it into RAMs and given to modules as initial inputs. By doing this we can reduce the large amount of memory usage in path finding algorithms and can save the time utilized for path calculation. This can improve the performance of wheelchair, and help to reduce the cost. We can also reduce the chance of error occurring due to wrong path calculation caused by any fault occurred in path finder module. The CUR_F is a flag which goes high when wheelchair covers 1m distance. The directions North, East, South and West represented using numbers 0, 1, 2 and3 respectively. The cur_grid gives the current position of wheelchair and get update with movement of wheelchair. Path count gives the number of grids to be covered by wheel chair so that it reaches the destination correctly. Dest_rchd is another flag to indicate whether wheelchair reached the destination correctly. The 4 signal fwd(forward), bkd(back ward), left and right are signal used by motor controller to generate control signal for motor driver IC. Then the verilog code is synthesised in Xilinx 12.1 tool for device Spartan 6 embedded kit.

TABLE I. DEVICE UTILIZATION SUMMORY

DEVICE UTILIZATION SUMMORY (ESTIMATED VALUES)			
Logic utilization	**Used**	**Available**	**Utilization**
Number of slice registers	393	54576	0%
Number of slice LUTs	994	27288	3%
Number of fully used LUT-FF pairs	331	1056	31%
Number of bonded IOBs	21	218	9%
Number of blockRAM/FIFO	1	116	0%
Number of BUFG/ BUFG CTRL	1	16	6%

The Table I shows the device utilization summary. Where RAM/FIFO utilized in system is 0%.994 slice LUTs are used out of 27288 available. The Fig. 8 shows the timing summary as obtained after synthesis.

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Timing Summary:
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Speed Grade: -3

   Minimum period: 8.457ns (Maximum Frequency: 118.242MHz)
   Minimum input arrival time before clock: 6.320ns
   Maximum output required time after clock: 6.941ns
   Maximum combinational path delay: No path found
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Fig. 8. Timing summary obtained after synthesis

V. DISCUSSION

The path finder module evaluated using different grid dimensions so that to check its performance. Grid dimension of 16x16 to 1000x1000 were checked. For most cases 64x64 sized floor plan will be more than sufficient for indoor navigation. From TABLE.II we can see that as per the grid number increases time for computation also increases but compared to other system using path finding modules for path calculation it is less in values.

TABLE II. COMPUTATION TIME IN MATLAB

Floor dimension	Tc (Intel i5 microprocessor and Matlab R2013a)
16 x16	.034721s
32x32	.048572s
64x64	.049979s
128x128	.085730s
256x256	.324358s
512x512	2.358626s
1000x1000	17.68000s

The FPGA controller is also tested for different grid dimensions of size 32x32 and 64x64. The fig.15 shows the device utilization obtained while synthesizing for a grid plan of 64x64. Compared to 16x16 grid plan the number of utilization of slice registers, LUT-FF pairs and LUTs have increased. The minimum time period needed is 8.637ns where as for grid dimension 16x16 is 8.457ns. The device utilization and minimum time period is going to increase with grid dimensions but will be less than the systems with path finding algorithm. Thus complexity in connections can also be reduced since there is not much devices to be connected.

TABLE III. DEVICE UTILIZATION SUMMARY OBTAINED WHILE SYNTHESISING A FLOOR PLAN OF 64X64 DIMENSIONS.

DEVICE UTILIZATION SUMMORY (ESTIMATED VALUES)			
Logic utilization	**Used**	**Available**	**Utilization**
Number of slice registers	466	54576	0%
Number of slice LUTs	1153	27288	3%
Number of fully used LUT-FF pairs	424	1056	31%
Number of bonded IOBs	21	218	9%
Number of blockRAM/FIFO	1	116	0%
Number of BUFG/BUFGCTRLs	1	16	6%

VI. CONCLUSION

The proposed design is tested at simulation level, both with Matlab and Verilog HDL. The user can choose the optimum path from source to destination in advance and store it in the memory which can be used later. As no algorithm is involved for computing the path, the computational complexity will be zero. The limitation of the system is that it can go only in fixed paths. This might not be a limitation, in case of users where they move from one room to another room many times in a day.

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