

# Reconfigurable Autonomous Mini Robot Design using CPLD's

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**Abstract**—This paper explains a project based learning method where autonomous mini-robots are developed for research, education and entertainment purposes. In case of remote systems wireless sensors are developed in critical areas, which would collect data at specific time intervals, send the data to the central wireless node based on certain preferred information would make decisions to turn on or off a switch or control unit. Such information transfers hardly sums up to a few bytes and hence low data rates would suffice for such implementations. As a robot is a multidisciplinary platform, the interfacing issues involved are discussed in this paper. The paper is mainly focused on power supply, grounding and decoupling issues.

**Keywords**—CPLD, power supply, decoupling, grounding.

## I. INTRODUCTION

An electromechanical device that can perform automated tasks, in many different forms, either with direct human supervision, a pre-defined program, or a set of general guidelines using some intelligence techniques. Working with robots is really a fun as well as challenging. Lot of work is conducted in this area from entertainment level to research level.

Robot designers need to be imbued with the knowledge of electronic design, analysis and software development. Furthermore, they have to be familiar with electronic components such as sensors, motors, logic devices, microprocessors and many others [1]. This paper reports a project based learning initiative where autonomous mini-robots are developed for research, education and entertainment purposes. Robot competitions in engineering education are vastly discussed and seen most common nowadays [2].

The main focus of this paper is to discuss the design issues with respect to ground, decoupling, power supply, interfacing issues and connections. The simple intelligent control is possible through any CPLD. But nowadays many applications demands latest wireless control techniques, which may be through for e.g. web or mobile.

## II. TYPICAL BLOCK DIAGRAM

The figure explains the idea of the system in brief. As shown in the block diagram the core is CPLD and the various other parts are explained as below.

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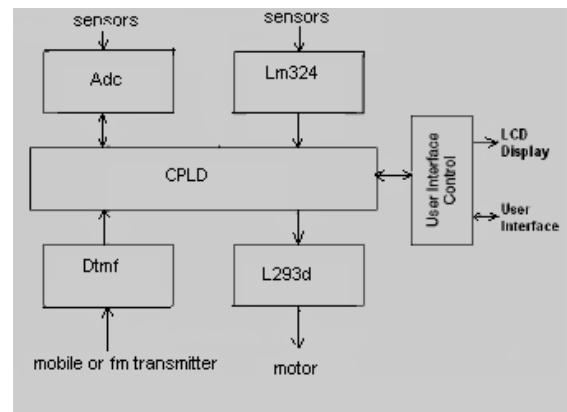


Fig. 1 Block diagram representation of CPLD controlled robot

## III. CONVENTIONAL DESIGN COMPONENTS

### A. CPLD

Normally a microcontroller plays an important role in all of today's robot designs in that they help in making the design programmable in a cost effective manner. Complex programmable logic devices (CPLD) are getting widely used because of their hardware re-configurability, programmability, low power and low cost.

CPLD's are made of small circuits called as macro cells, which contains logic implementing boolean expressions and more specialized logic operations. Thousands of such macro cells, every cell containing number of logic gates allow implementation of moderately complicated data processing devices in CPLDs. With LUT's and Macrocells more flexibility is achieved using complicated feedback paths to implement many commonly used functions and integer arithmetic. Unlike many Field Programmable devices, an external configuration ROM isn't required, and the CPLD can function immediately on system start-up thus making the CPLD's non volatile and become the choice of modern digital systems design.

Routing constrains most logic blocks to have input and output signals connected to external pins, reducing opportunities for internal state storage and deeply layered logic. [3]

The low cost, non-volatile configuration, and macro cells with predictable timing characteristics gives an architectural advantage for CPLDs which will be sufficient to maintain a lead in the hardware reconfigurable arena the foreseeable future.

The CPLD that is used for our design and generally preferable for designing of robots is cool runner-2 the family (XC2C32A)[4]. This CPLD have 56 product terms per macro cell and with 32 macro cells.

**B. Data flow diagram**

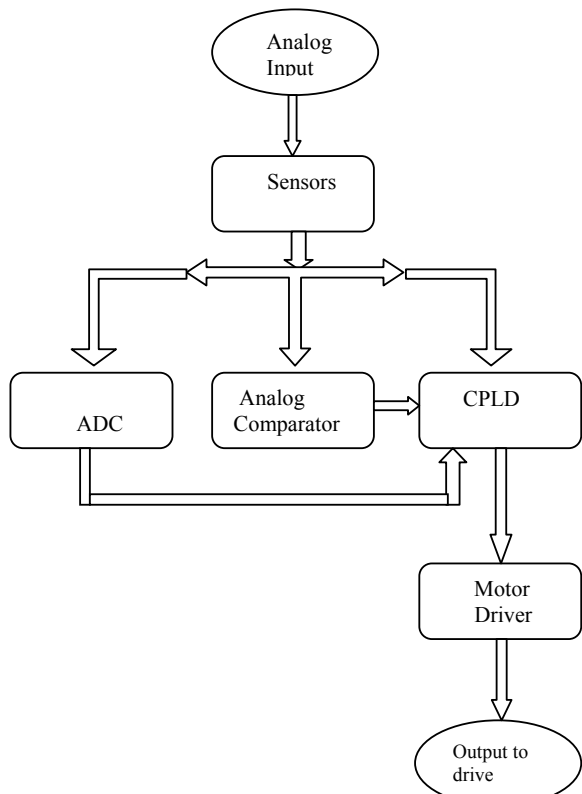


Fig. 2 Flowchart of the proposed design

**C. Analog Comparator**

Analog Comparator actually bridges the analog physical world with the digital world. It is an Op amp with faster slew rate and its output is optimized for switching purpose. Here we are using analog comparator as a threshold level detector to monitor a physical variable that is light intensity and a signal whenever the variable rises above or below a prescribed value called set value[5]. The detector output is then used to undertake a specific action. As the comparator is interfaced with the controller the working voltage has to be TTL compatible although the comparator can work with a wide range of voltage like the LM324 can work with 3-32 voltage range.

The voltage from input sensor can be compared against a reference voltage and a simple binary value, indicating that the analog value is above or below the reference passed to cpld. Analog voltage comparator takes linear, analog voltage and outputs a simple on-off signal to control the robot through cpld.[2].

To interface it with the CPLD one can use open collector configuration or totem pole output.

Open collector is normally used with LM324 whereas totem pole output is aimed at logic applications.

As this block requires low voltage supply separate analog and digital grounds should be established and connected only at one point. The analog and digital sections of the circuit should be physically separated with no digital tracks which transverse the analog section and vice versa. This will minimize cross talk between the circuits.

Once the input signals are in digital form they act as the input data to cpld operation. It is the source data of output decision.

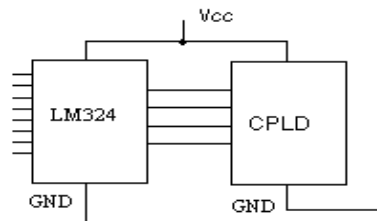


Fig. 3 Analog comparator configuration

**D. Motor Driver**

Similar precautions as input stage are to be taken for the output stage, for the reverse reason, as output is the cause of interference. As output stage means motor driver stage [5] is operating at high currents and higher voltages and therefore the possibility of unwanted feedback.

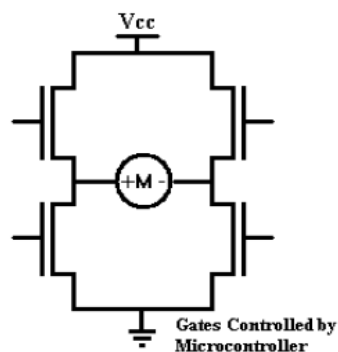


Fig. 4 Motor driver control through gates of transistors

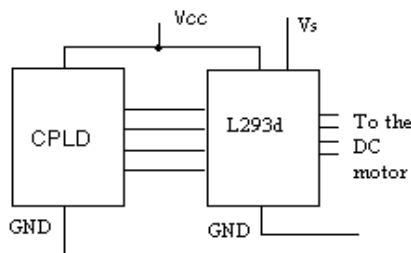


Fig. 5 Motor driver - Configuration diagram

This stage should be having its own separate PCB designed with separate tracks, because it may have high current. DC motors also exhibit back emf effects and so driving them with transistors it is wise to use catch diodes. DC motors cause

electromagnetic interference problems if the communicator is not suppressed with capacitor of 100 nano farad 50V/100V disc ceramic capacitor soldered directly across the contacts on the motor will be adequate.

As motor driver requires higher voltage the supply voltage given to Vcc of power transistors should be directly connected to supply and to drive internal switching transistors the comparatively low voltage is directly provided by the separate supply.

*E. Analog to Digital Convertor*

Interfacing ADC with CPLD itself is big challenge PCB layout is often critical for successful design of ADC circuits. The main very important point to be considered is speed and frequency mismatched between ADC and controller. Resolutions of more than 12 bits are less tolerant of noise simply because 1 LSB is of the order of 1mV or less.

Grounding is the key to success as with small signal, the proximity of digital switching waveforms, inherent in design of ADC and oscillator cpld circuitry that makes noisy environment. So, careful decoupling of supplies, segregation of analog and digital ground and avoiding ground loops are very much important.

*F. Decoupling*

The purpose of decoupling is to maintain low dynamic impedance from individual IC supply voltage to ground. No matter how good the VCC and ground connections are, you cannot eliminate all line inductance. Except on the smallest boards, track distance will introduce impedance that will create switching noise from the transient currents. This is the reason for decoupling. The minimum value of capacitor can be calculated using formula

$$C=I.t/V$$

The minimum requirements for decoupling are

- One 22µF capacitor per board
- One 10-100 nF ceramic multilayer capacitor for each supply pin using different supply voltages.

In this way we can calculate the requirements for individual power speed-hungry devices to make sure that circuit has enough capacitors in the right places.

Decoupling capacitors are to be connected as close to IC pins as possible. When the circuit contains IF and RF parts in it then to retain stability at high gain, decoupling must be carefully followed. Normally, for decoupling or for RF coupling ceramic capacitors are used. Discrete decoupling capacitors are required for mid frequency decoupling.

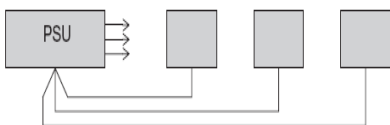


Fig. 6 Right ground track connection

*G. Grounding*

The main problem of output ground coupling is they both share a common impedance so output signal returns should be as shown in figure 6.

Grounding is always sensitive to layout. The width of ground tracks should be in the 3:1 proportion.

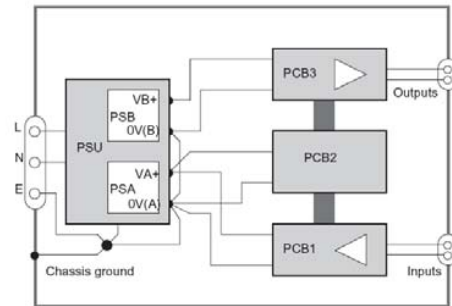


Fig. 7 Ideal powers supply connections

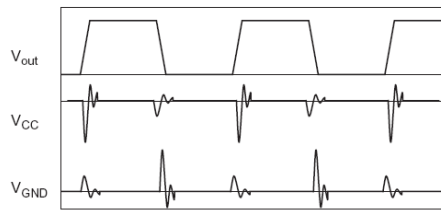


Fig. 8 Switching noise on power and ground rails

Every track on PCB generates its own inductance which is often misleading as it will be modified by proximity to other tracks carrying return currents [6]. It shows the principle of magnetic field cancellation of two close tracks carrying equal but opposite currents. It follows the Maxwell's equation

$$\nabla \cdot \mathbf{B} = 0$$

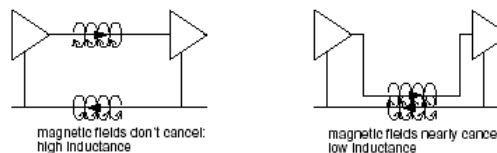


Fig. 9 Mutual Inductance

Fig. 9 shows the effect of mutual inductance. The second figure is the correct arrangement of the ground lines.

Here, total inductance within loop is zero. This gives most effective way of reducing total power and ground inductance is to run the signal and return paths very close together.

*H. Sensors*

By the most common use of inputs in robotics are sensors. Mainly there are two types of sensors

1. Analog sensors
2. Digital sensors

In case of analog sensors additional circuitry is required to convert varying voltage levels in the form that a control

computer can use. For this purpose we can use a analog comparator or ADC.

But in case of digital sensors no need to add any additional circuits. These sensors can be directly connected to cpld because the output is directly compatible

**I. DTMF transceiver**

DTMF provides low power dissipation and high reliability. The MT8880C, DTMF transceiver [5] employs a microprocessor interface that allows precise control of transmitter and receiver functions. By collecting data at specific time intervals, and sending the data to the controller to take decisions to turn on or off a switch or control unit. Such information transfers hardly sums up to a few bytes and hence low data rates would suffice for such implementations.

There are five internal registers associated with the microprocessor interface which can be subdivided into three categories, i.e., data transfer, transceiver control and transceiver status[6]. There are two registers associated with data transfer operations. Microprocessor based systems can inject undesirable noise into the supply rails. The performance of the MT8880 can be optimized by keeping noise on the supply rails to a minimum. The decoupling capacitor should be connected close to the device and ground loops should be avoided. Input capacitor is used here in series with the input pin to pass the DTMF signal and to block the undesired dc component.

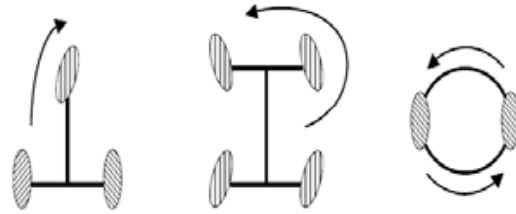


Fig. 11 A: the tricycle, B: the quad (four wheel steer version), C: the wheelchair (below also)



With the wheelchair Configuration it is possible to design the chassis so that these turns can be executed on the spot. Both the tricycle and quad moves away from the driving wheels during acceleration and/or braking. They can also cause surface damage and introduce a large strain on the steering components if turning is executed while it is stationary. The control of a device that is implementing either of these systems can also be complicated if it is required.

**V. RESULTS**

The test control logic was written in VHDL and implemented in Xilinx Cool Runner CPLD. The observed and analysed results are shown below.

TABLE I  
ROBOT COMPONENT FUNCTIONS AND CORRESPONDING CPLD AREA

I/O Blocks	Macrocells Used	Pterms Used	Registers Used	Pins Used	Function Block
Sensor	2/108 (2%)	2/540 (1%)	0/108 (0%)	4/69 (6%)	2/216 (1%)
Adc	30/108 (28%)	75/540 (14%)	11/108 (11%)	30/69 (44%)	37/216 (18%)
Dtmf	2/108 (2%)	2/540 (1%)	0/108 (0%)	4/69 (6%)	2/216 (1%)
Pwm	11/108 (11%)	39/540 (8%)	8/108 (8%)	11/69 (16%)	19/216 (9%)
Motor	6/108 (6%)	12/540 (2%)	0/108 (0%)	10/69 (12%)	8/216 (4%)

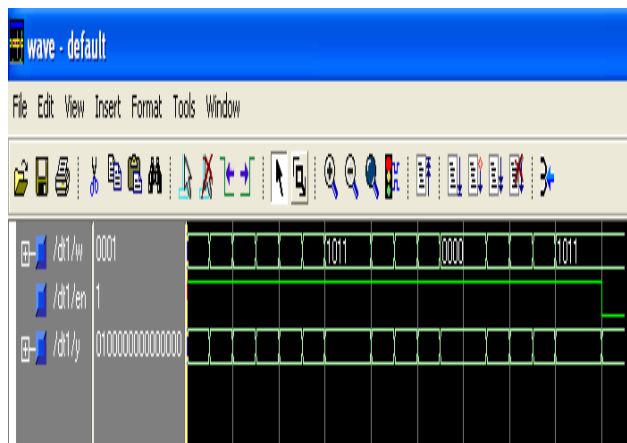


Fig. 10 Test Bench Waveform of DTMF

**IV. HOLONOMIC WHEEL STRUCTURES**

Three different mechanical designs are under construction[7], differential steering, Ackerman steering and Omni wheel steering (Holonomic Structure).

**A. Holo-nomic structure.**

The wheelchair configuration is preferred to the quad and tricycle because of the tighter Turning circle, which is required to perform 90 and 180-degree turns in the confines of an office block corridor.

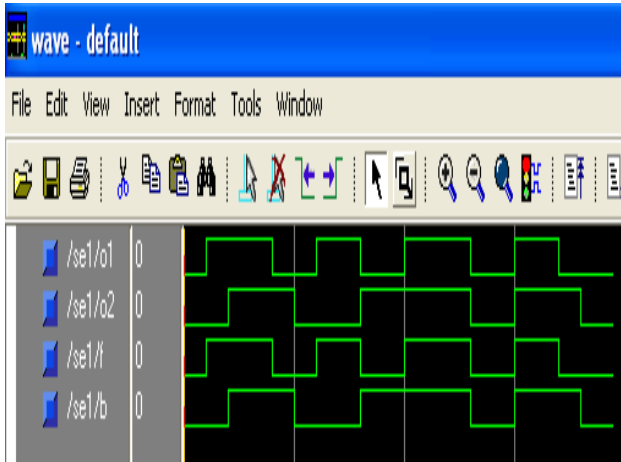


Fig. 12 Test Bench Waveform of Analog Comparator in Modelsim simulator.

TABLE II  
ROBOT COMPONENTS AND RESULTS PROPERTY COMPARISON

CIRCUIT USED	POWER CONSUMED	FREQUENCY OF OPERATION	TYPE OF CIRCUIT
CPLD	Low	High	Digital
Analog Comparator	Low	Low	Analog
Motor Driver	High	Low	Mixed
ADC	Low	High	Mixed
DTMF Transceiver	Low	High	Mixed

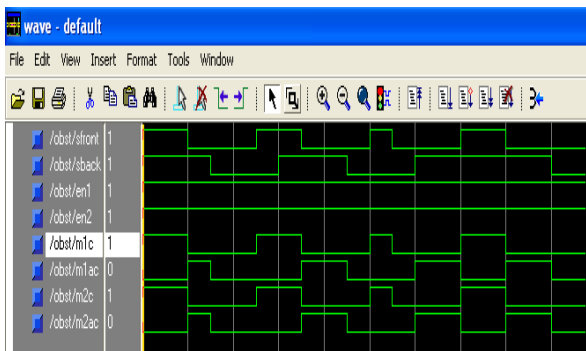


Fig. 13 Test Bench Waveform of Motor

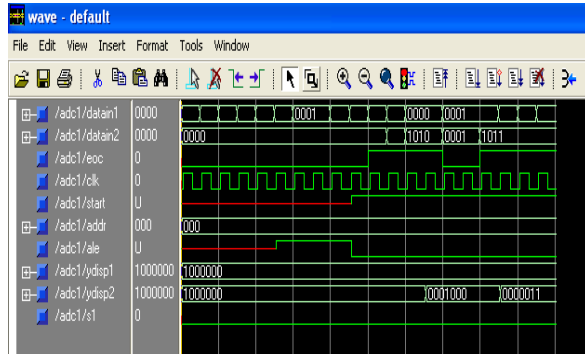


Fig. 14 Test Bench Waveform of ADC

VI. CONCLUSION AND FUTURE WORK

Quantitative and qualitative analysis of the mobile robot was carried out. The sensors, motor driver, ADC circuits were examined. All the circuits made are configurable so the whole system has high flexibility and high efficiency in future also.

The individual chips used can be a part of single chip as a System On Chip (SoC) for Mobile Robots.

Future work can be concentrated on SoC design of the whole circuit so we can control analogue as well as digital devices within a single chip.

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