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A VHDL application for kinematic equation solutions of multi-degree-of-freedom systems

Key words: Multi-degree-of-freedom systems, Kinematics, Co-processor, Serial communication, Six-legged robot

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Introduction

- As kinematic calculations are complicated, it takes a long time and is difficult to get the desired accurate result with a single processor in real time
- Designed systems are also complicated because they have many parts and cabling
- This paper presents the design and implementation of a hardware that will provide solutions to these problems
- This hardware is designed for a six-legged robot and has been working with servo motors controlled via the serial port
- This hardware has a co-processor for the calculation of kinematic equations and can be used together with the equipment that would reduce the electromechanical mess
- It is intended to be used as a tool which will accelerate the transition from design to application for robots

Mechanical structure and kinematic equations

Denavit-Hartenberg parameters for three-joint legs

i	α_i (°)	a_i (mm)	d_i (mm)	β_i
1	0	0	0	β_1
2	90	60	0	β_2
3	0	80	0	β_3

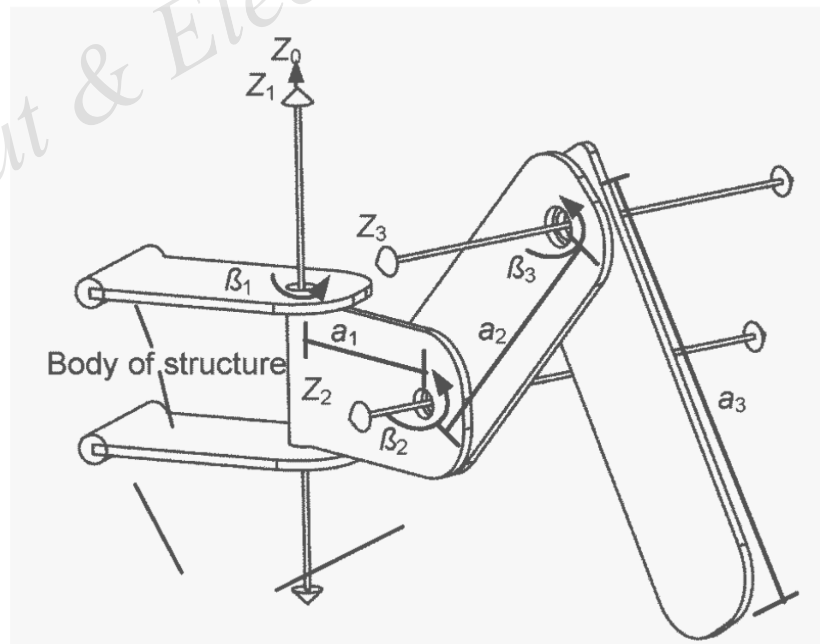
$$T_3^0 = \begin{bmatrix} c_{23}.c_1 & -s_{23}.c_1 & s_1 & c_1(a_2.\mathrm{c}_2 + a_3.\mathrm{c}_{23}) \\ c_{23}.s_1 & -s_{23}.s_1 & -c_1 & s_1(a_2.\mathrm{c}_2 + a_3.\mathrm{c}_{23}) \\ s_{23} & c_{23} & 0 & a_3.\mathrm{s}_{23} + a_2.\mathrm{s}_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$P_x = (d_2 + d_3).\mathrm{s}_1 + a_2.\mathrm{c}_1.\mathrm{c}_2 + a_3.\mathrm{c}_1.(\mathrm{c}_2.\mathrm{c}_3 - \mathrm{s}_2.\mathrm{s}_3)$$

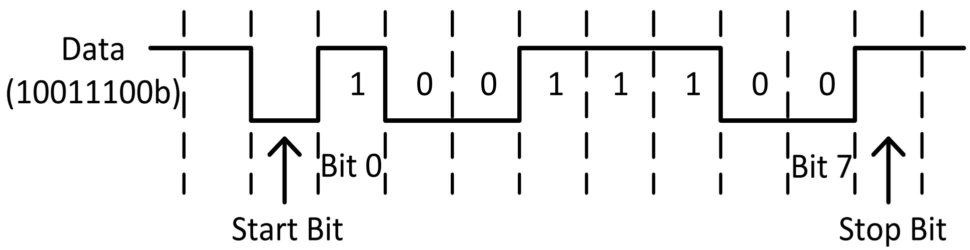
$$P_y = -(d_2 + d_3).\mathrm{c}_1 + a_2.\mathrm{s}_1.\mathrm{c}_2 + a_3.\mathrm{s}_1.(\mathrm{c}_2.\mathrm{c}_3 - \mathrm{s}_2.\mathrm{s}_3)$$

$$P_z = a_3.\mathrm{s}_{23} + a_2.\mathrm{s}_2$$

$$\beta_N = \arctan\left(\frac{s_i}{c_i}\right)$$



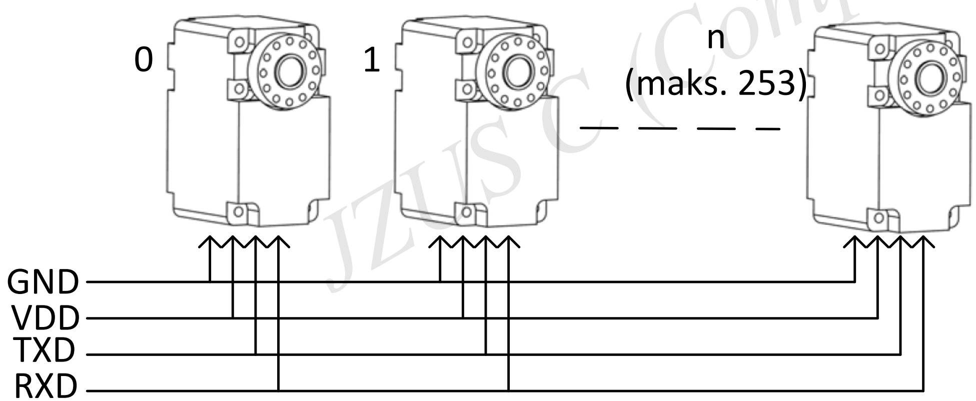
Motors controlled via serial port



Data transmission signal

Pin descriptions of motor connector

Pin number	Name	Description
1	GND	Electrical ground connection
2	VDD	Supply voltage
3	TXD	Transmitting line
4	RXD	Receiving line

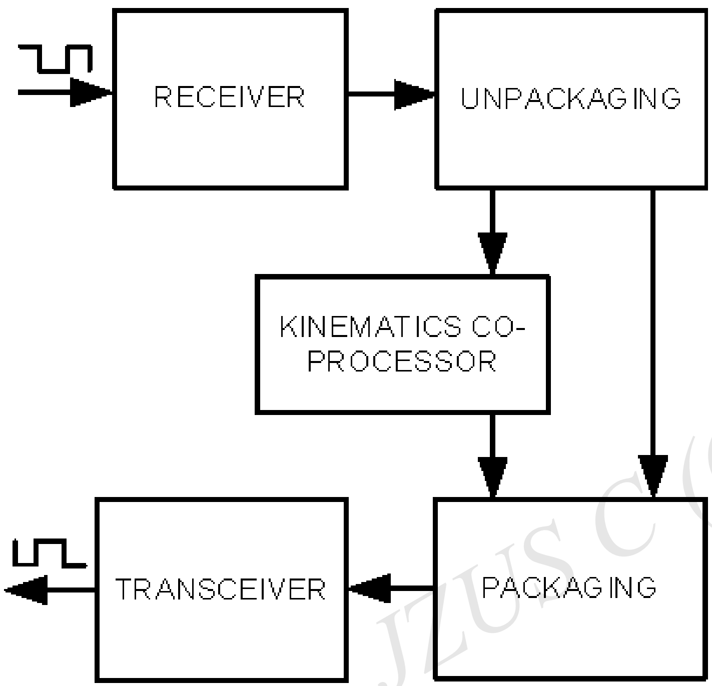


Motor connections

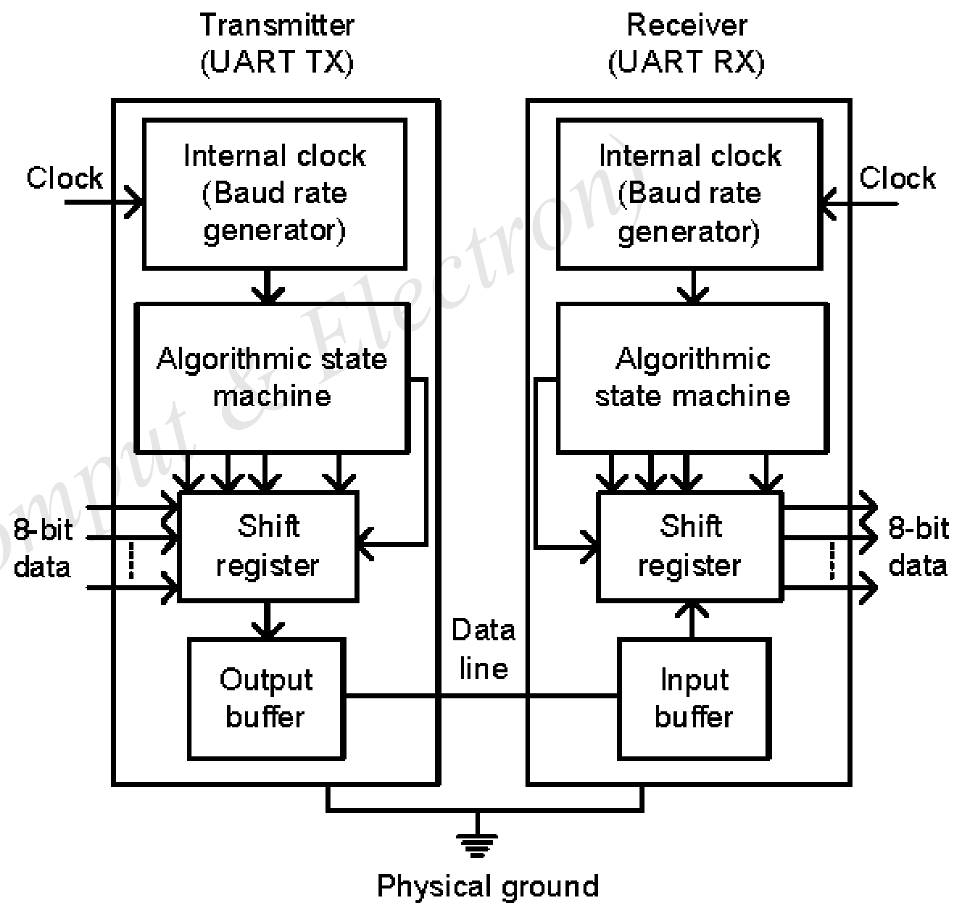
Details of communication packet

	Header	Pack size	pID	CMD	Check Sum1	Check Sum2	Data [n]
Value	0xFF 0xFF	7-223	0-0xFE	1-9	-	-	-
Length (byte)	2	1	1	1	1	1	Maks. 216

Recommended structure of chip

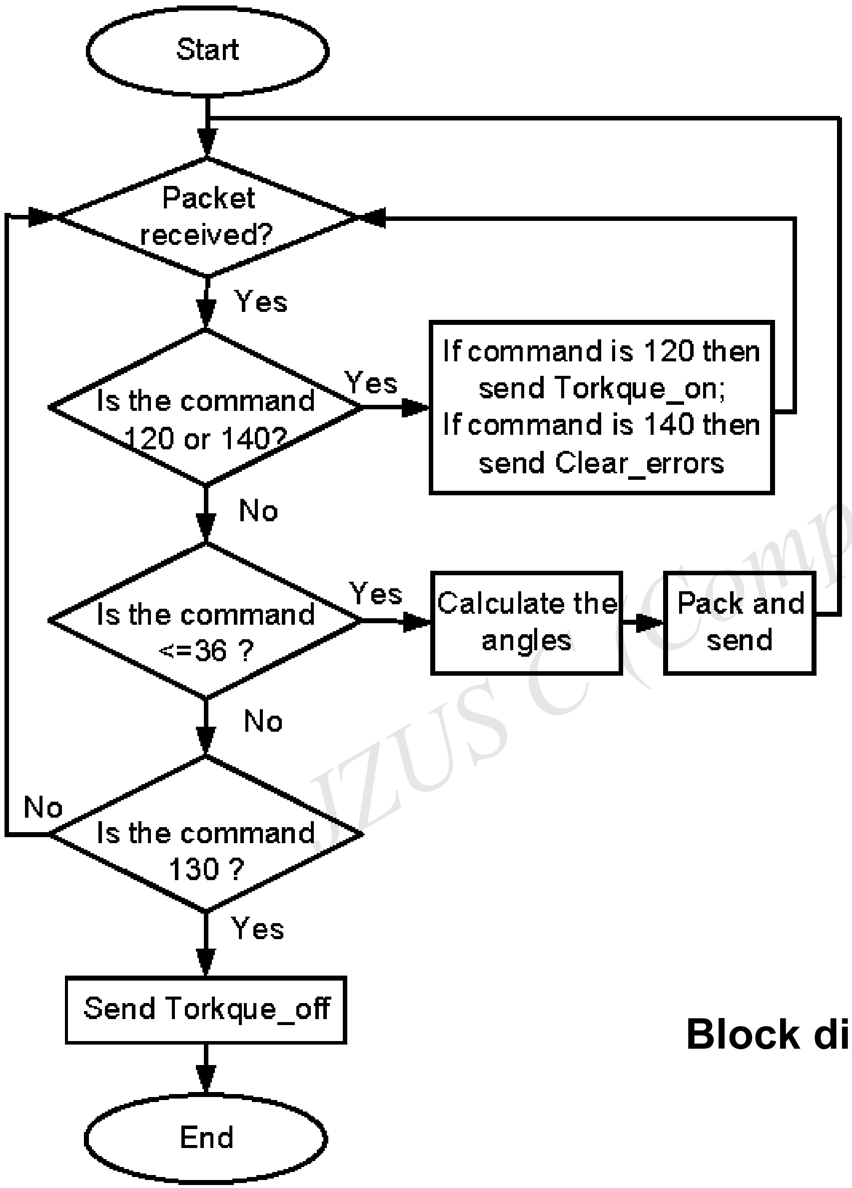


Block diagram of design



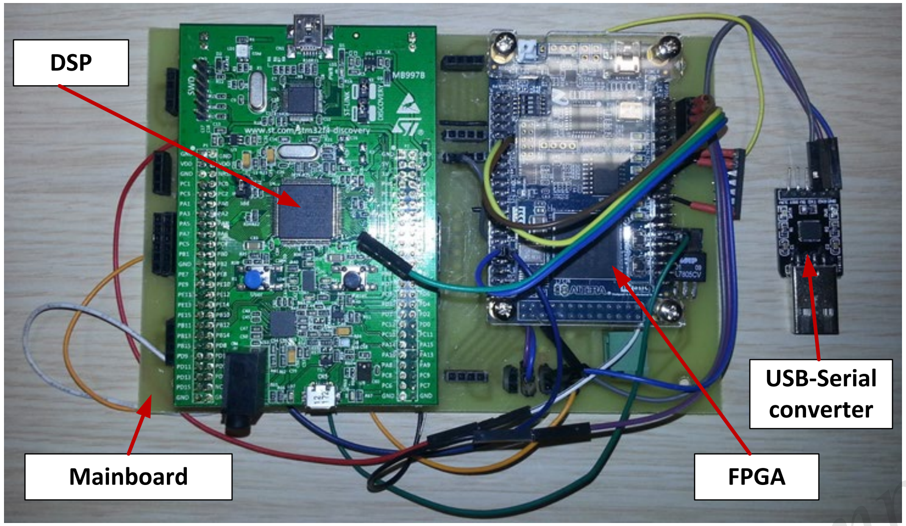
Block diagram of transmitter and receiver

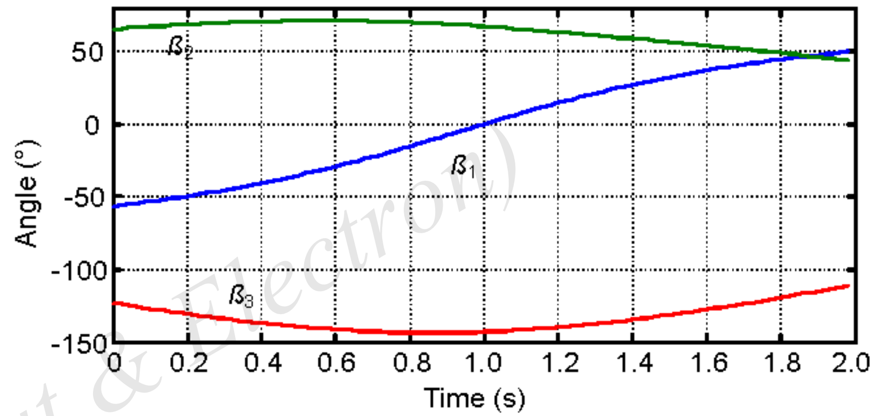
Recommended structure of chip



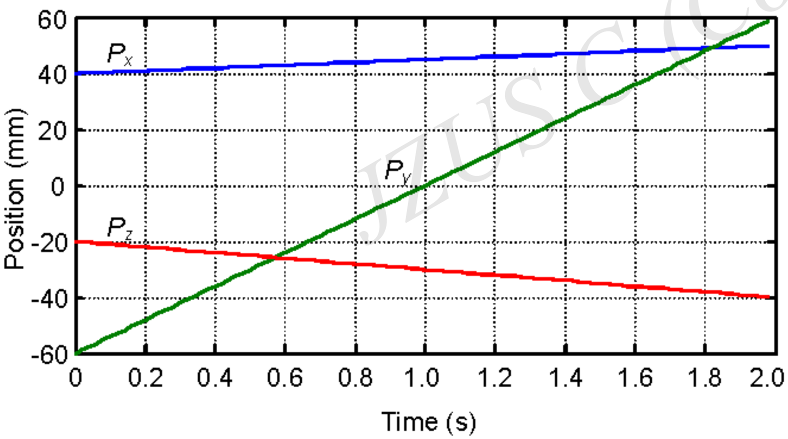
Block diagram of process

Hardware test

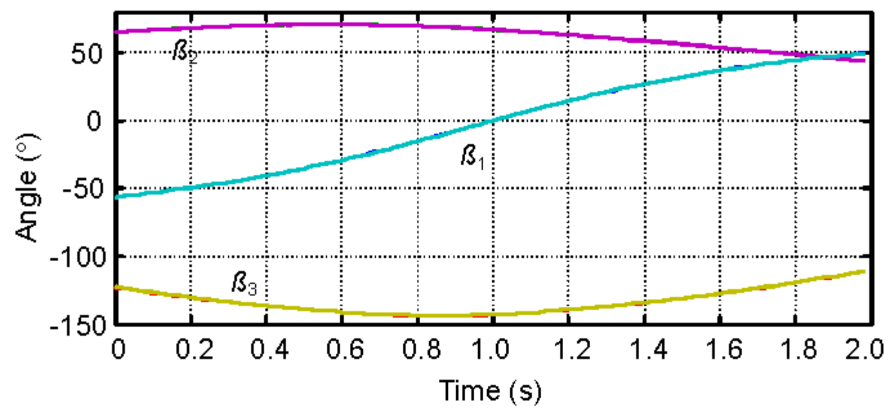




Changes in joint angles



X, Y, Z positions of the foot



Comparison of the performed design's output signals with simulation

Conclusions

- The designed hardware has a serial port and also a co-processor to perform kinematic calculations
- The application was performed on FPGA to meet the needs of real-time operation
- The designed hardware calculates the required joint angles to reach the foot positions received from the serial port. Then it sends the angles to the servo motors via the serial port
- Hardware has been developed for a hexapod robot. However, it can be used easily for another robot by changing the kinematic equations solved by the co-processor
- Using this hardware, the transition will be faster from design to implementation in experimental or commercial studies and the load on the main processor will be reduced