

Power and Propulsion Systems Design for an Autonomous Omni-directional Mobile Robot

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Abstract— In this paper power and propulsion systems design for an autonomous omni-directional mobile robot which is developed for RoboCup compaction, is presented. For robot energy storage unit, Lithium ion polymer battery is chosen because of its high power and energy densities, and a protection circuit against deep battery discharge was designed for it. Because the power flow between energy storage units and motors and also speeds of motors have to be controlled at the same time, we proposed a two cascaded cell modules consisting motor speed control and power flow control modules. The other parts of our robot power system are dc-dc converters and kicker circuit. The simulation and experimental results show proposed scheme is valid and energy management and speed control can be achieved properly using this method. The filed experiments show robot mobility functions to perform the requested motion is enough and it has a high maneuverability in the field.

I. INTRODUCTION

During the 21st century, it is expected that the robots will play an increasingly important role in all side of human life [1]-[2]. As the complexity of robots increases, they need more energy to perform their tasks and the management of this energy will be essential. Especially for any autonomous mobile robot that carries its own energy source, design of power and propulsion systems present a great challenge for researchers [3]. Since the mobile robots total power consumption is limited in the range of several watts to several tens of watts it is predicted that robots become the next driver of low power electronics and they provide the biggest challenges for this industry in the future [4] [5].

In this paper power and propulsions systems of an autonomous omni-directional mobile robot is presented. The proposed system is implemented in soccer robots for the RoboCup middle size league. The system of these soccer robots has been explained in [6] and [7] by authors previously. Robot soccer is considered a benchmark for the progress of robotics by providing standard problems where a wide variety of technologies can be integrated and examined [8] [9].

Because of the car-like locomotion poor mobility functions, we have used an omni-directional mobile platform which employs 3 omni-wheels. And to control these wheels,

propulsion system utilizes three permanent magnet DC motor with their motor drives and a system for power flow control. Because in this system, the ability of power flow control from of two separated energy storage units and speed control for each motor are combined, this robot can be derived by more than one power source. Although in this paper the proposed system is employed to drive robot with batteries, it can be applied to use in robots with hybrid power sources. The other parts of our robot power system are batteries, power supply, dc-dc converters, protection systems, and kicker circuit. In addition to energy of propulsion motors the batteries provide the required energy of micro controller, USB-Hub, USB-RS232 converter, and kicker. The simulation and experimental result shows the energy management and speed control can be achieved properly using proposed method. The robot omni-directional movement is achieved using proposed power and propulsion systems. And the omni-directional dynamical and kinematics characteristics allow for a high maneuverability in the field.

These robots are made by “Hibikino-Musashi” which is a joint RoboCup middle-size league soccer team. Members of the team are from three different research and educational organizations located in the Kitakyushu Science and Research Park, Kitakyushu, Japan¹. These robots could get the 1st and 2nd place at RoboCup Japan in 2006 and 2007 respectively and was ranked among the best 4 teams at world championship in 2007. As well our team can get award from Robotics Society of Japan.

II. POWER SYSTEM

Fig.1 shows the flowchart of the robot power system including a main Li-Polymer battery (25.9 [V]) and two extra Li-Polymer battery (7.4 [V]) as auxiliary power for high acceleration and speed during catching and carrying a ball. The necessary voltage for the camera and the micro computer

¹ The three organizations are: Kyushu Institute of Technology, The University of Kitakyushu, and Kitakyushu Foundation for the Advancement of Industry Science and Technology.

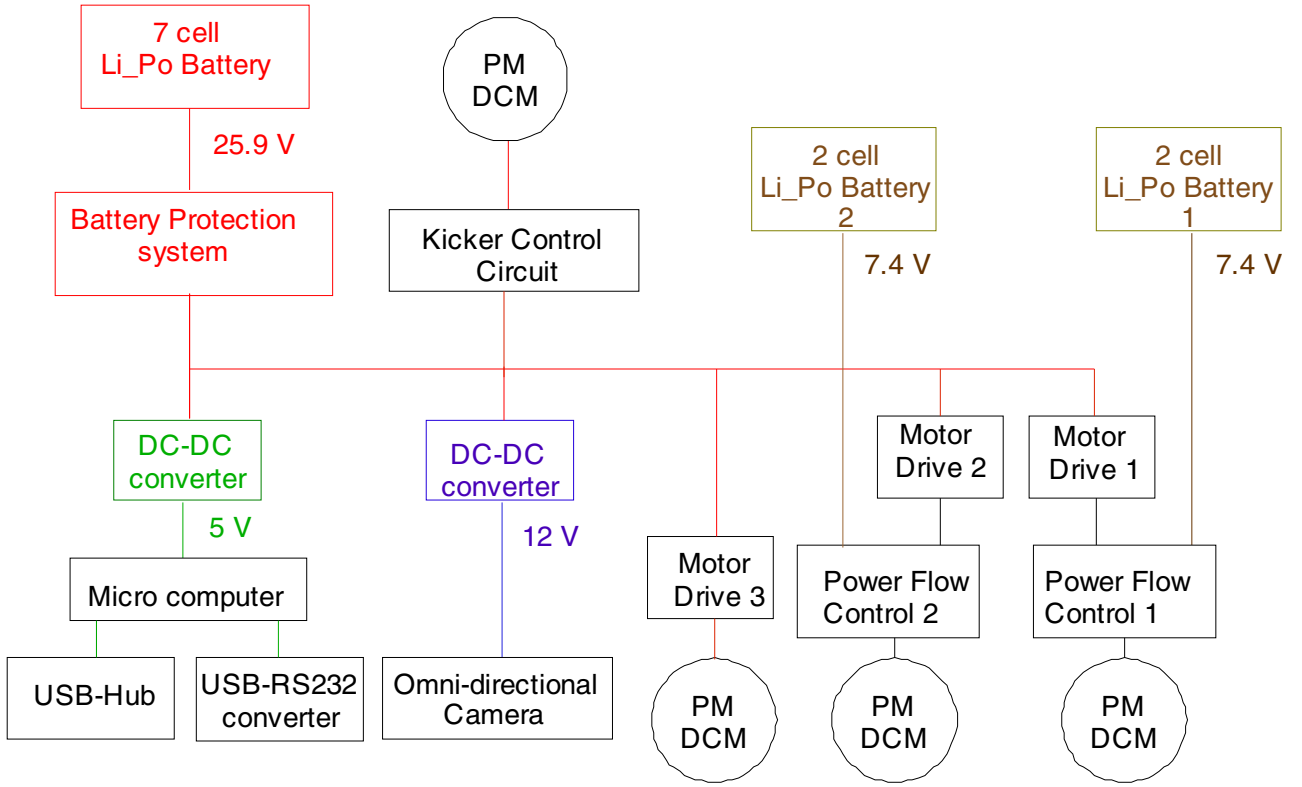


Fig.1 Flow chart of our robot power system

power supply are converted from 25.9 [V] to 12.0 [V] and 5.0 [V], respectively. The power consumption of the robot is approximately 40 [W] and the operation estimated duration of the robot is 0.5 [h].

III. ENERGY STORAGE UNITS

Like as energy storage requirements for electrical vehicles which are expressed in [10] [11], the robot electrical storage unit must be sized by an energy storage and power requirement. Therefore the robot battery performance characteristics (Energy/weight Energy/size and Power/weight) should be enough to store sufficient energy and to provide the necessary peak power. After calculation of necessary power and energy for our robot we chose Lithium ion polymer batteries because of its high power density (2220 W/kg) and high energy density (185 Wh/kg) [12]. The nominal voltage of each cell is 3.7 volt. One 7 cell (25.9 V) and two 2 cell (7.4 V) batteries have been used in this system. This battery should not be discharged to a level below 3V per cell under load, because deep discharge below 3V per cell can deteriorate battery performance [12]. Therefore To avoid of battery damage, a protection circuit against deep battery discharge was designed and was employed in robot.

IV. POWER FLOW CONTROL

As mentioned previously, in addition to main battery, there are two auxiliary batteries in robot power system ,which are

utilized when robot needs high acceleration and speed during catching and carrying a ball. Because the power flow between these batteries and motors and also motor speeds should be controlled at the same time, we proposed a two cascaded cell modules consisting motor speed control and power flow control modules. Power flow control using cascaded converters has been used in multilevel inverters previously [13] [14] [15].

As seen in Fig.2 in proposed system for each forward motor, there are two cascaded modules, one module which consist of main battery and a PWM inverter, control the motor speed and the another one manages the delivered energy from auxiliary battery.

For this cascaded modules the output power of each auxiliary battery (P_{BB}) and output mechanical power (P_{mech}) are calculated in (2) and (3) using (1).

$$P_{BB} = V_{BB} I \quad (1)$$

$$P_{mech} = (V_T - R_a I) I \quad (2)$$

$$V_T = V_{BB} + V_{inv} \quad (3)$$

Where V_T , V_{BB} and V_{inv} are motor terminal, battery and inverter voltages respectively and I is motor, battery and inverter current.

And then the relation of P_{BB} and P_{mech} is achieved in

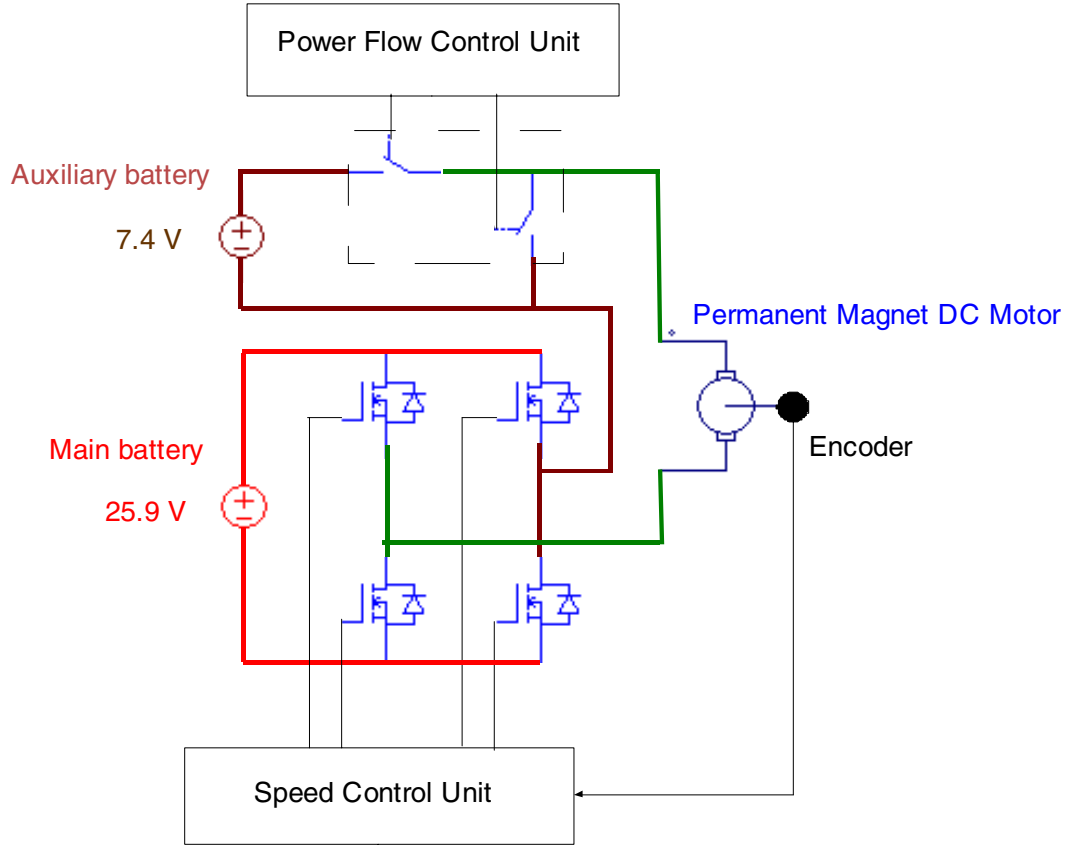


Fig.2 Power flow control and speed control system

(5) using (1)-(4).

$$\omega = K_{\omega} (V_T - R_a I) \quad (4)$$

$$P_{BB} = P_{mech} \frac{K_{\omega} V_{BB}}{\omega} \quad (5)$$

Where K_{ω} and ω are speed constant and angular speed of motor respectively.

Because the robot moves with maximum speed (1.9 [m/s]) during utilizing auxiliary batteries, the motor speed and motor power is almost do not change and they could be assumed constant. Therefore the delivered energy from battery with constant speed (E_{BBc}) is calculated as follows.

$$E_{BBc} = \int_{T_{on}} P_{mech} \frac{K_{\omega} V_{BB}}{\omega} dt = P_{mech} \frac{K_{\omega} V_{BB}}{\omega} \Delta T \quad (6)$$

$$E_{mechc} = \int_T P_{mech} dt = P_{mech} T \quad (7)$$

$$E_{BBc} = \frac{V_{BB} K_{\omega}}{\omega} E_{mechc} \times \frac{\Delta T}{T} \quad (8)$$

Where ΔT , T and E_{mechc} are the time interval of auxiliary batteries utilizing, total time of robot movement with speed ω and mechanical energy produced by motor respectively.

In start up condition the robot acceleration and consequently the motor torque (τ) and motor angular acceleration (α) are constant. Therefore for time interval of motor startup (T_s) equations (9) - (11) can be written.

$$E_{BBs} = \int_{\Delta T} \tau \omega \frac{K_{\omega} V_{BB}}{\omega} dt = \tau K_{\omega} V_{BB} \Delta T \quad (9)$$

$$E_{mechs} = \int_{T_s} \tau \omega dt = \int_{T_s} \tau \alpha t dt = \frac{1}{2} \tau \omega T_s \quad (10)$$

$$E_{BBs} = \frac{2 V_{BB} K_{\omega}}{\omega} E_{mechs} \times \frac{\Delta T}{T_s} \quad (11)$$

Where E_{BBs} and E_{mechs} are delivered energy to motor and motor mechanical energy in startup condition respectively.

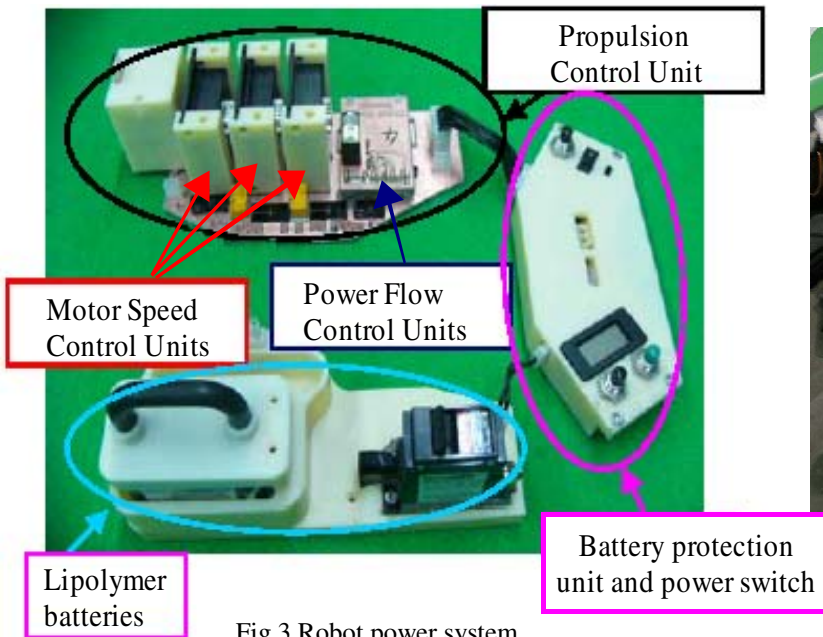


Fig.3 Robot power system



Fig.4 Our Autonomous Robots

As seen in (8) and (11) the delivered energy control from of inverter supplied by main battery, and auxiliary batteries can be achieved by adjusting the time interval of auxiliary batteries utilizing.

are shown in Fig.3. Fig.4 shows developed autonomous omni-directional mobile robots. And the specification of the dc permanent magnet motor is shown in the table 1.

TABLE I. PMDC MOTOR NOMINAL PARAMETERS

Rated Power	70 W
Rated Torque	88.2 mNm
Rated Current	2.25 A
Torque Constant	36.4 mNm/A
Speed Constant	263 rpm/V
Terminal Inductance	0.201 mH
Terminal Resistance	1.11 Ω
Nominal Voltage	24.0 V

V. EXPERIMENTAL SYSTEM SETUP

Each robot is equipped with 3 omni-wheels, each of them driven by a permanent magnet dc motor. Gearboxes with reduction ratios of 18:1 are used to reduce the high angular speeds of the motors (7000 rpm) and to amplify the wheels torque. Each motor has a 540 [ppr] digital incremental encoders. A laptop PC sends the motor control commands (target and velocity) to the motor drivers. The robot can move with maximum speed of 1.9 [m/s] and acceleration of 2.5 [m/s²]. The major parts of robot power and propulsion systems

VI. SIMULATION RESULTS

To analysis the validity of proposed control method, the robot propulsion system is simulated using MATLAB-SIMULINK. The simulated system which is shown in Fig.5 includes PWM inverter, Energy management system, PI speed control and dynamic model of permanent magnet DC motor. The simulation results for $\Delta T = T$ and for 5000 rpm are shown in Fig.6. This figure shows the equation (8) is valid, because for this system equation (8) results $E_{BBc} = 0.3892E_{mechc}$.

VII. EXPERIMENTAL RESULTS

The experimental results for $\Delta T = T$ and 5000 rpm are shown in Fig.7. This results show experimental and simulation results are same and the equation (8) is valid. It can be seen that, the speed control unit changes the output voltage to set the motor speed to reference speed. Thus speed control and power flow control can be achieved.

VIII. CONCLUSIONS

In this paper power and propulsion systems design for an autonomous omni-directional mobile robot is presented. In this system the ability of power flow control from of two separated energy storage units and speed control for each motor are combined. To avoid of Li-Polymer batteries damage a protection system against deep discharge is designed. The

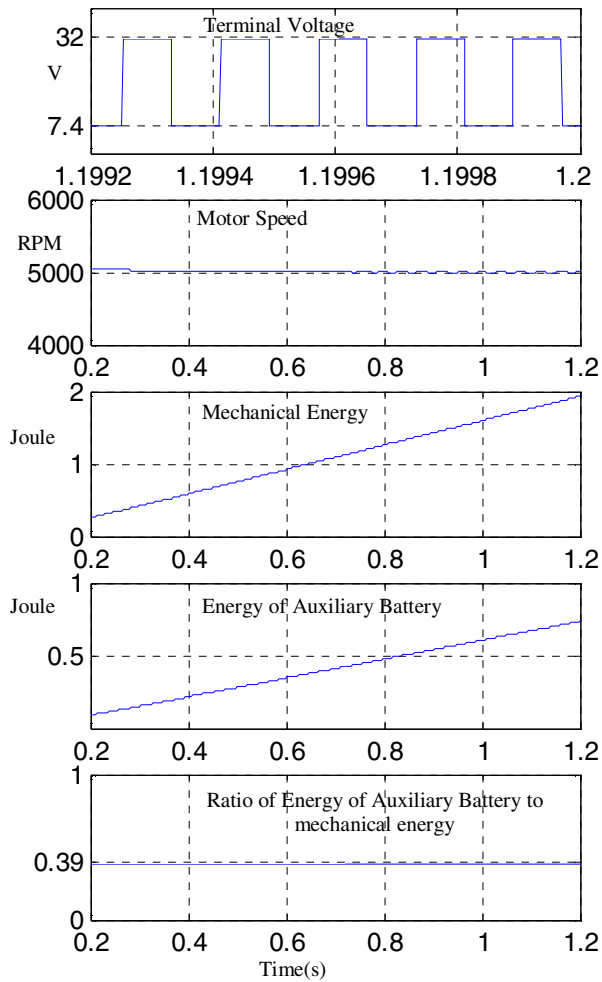


Fig.6 Simulation results for $\Delta T = T$ and 5000 rpm

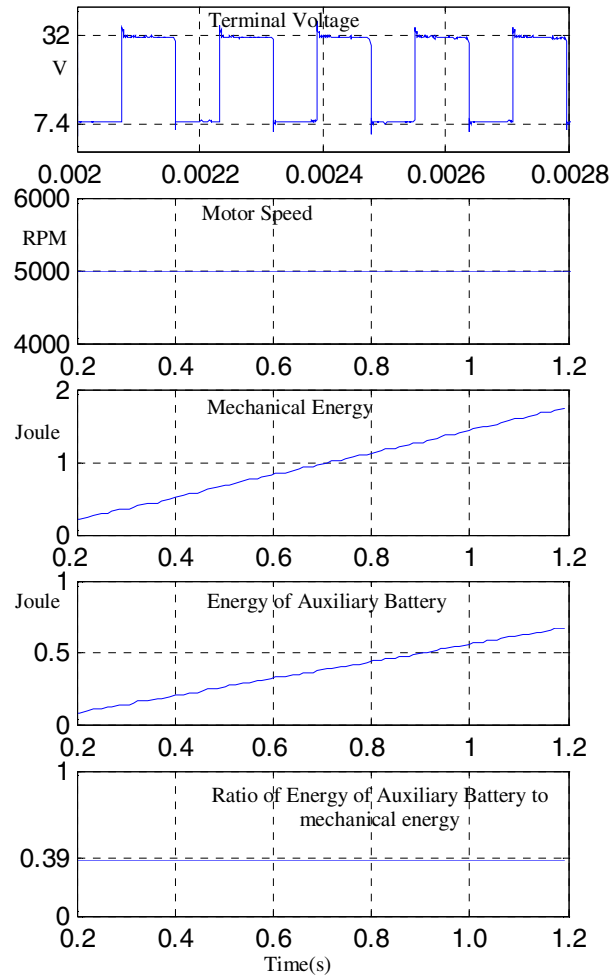


Fig.7 Experimental results for $\Delta T = T$ and 5000 rpm

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