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Battery Charging Effect Mobile Robot Performance in Discharge Terms Mathematically

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***Abstract*—NiCD and NiMH batteries were used on two similar mobile robots of indigenous design named Spark V which varied the weight to torque ratio and the performance was compared in terms of run time and also their overall performance. This work found some interesting analysis in terms of run time being higher for a NiCd battery although NiMH which is a very well established battery on most mobile robot platforms. Interestingly, the NiCd installed was a cordless headset battery that could drive the robot longer when compared to standard NiMH.**

***Index Terms*— battery management, mobile robot, spark V Robot.**

I. Introduction

The performance of the mobile robot with different batteries is an important aspect when the systems are autonomous in nature. Autonomy of robots is very much dependent on the way the power management of the robot is managed. Power management is very well defined with the way the batteries are developed, used(charging and discharged) and also in mobile robots the weight of the robot plays an important role.
Rohini et al[1] discusses about Proprioceptive sensors and the need for measuring battery voltage value which is an important parameter in the analysis of unmanned vehicles. Skubic et al[2] has defined and understood the problems associated with robots working as a team and it was found power management of robot is crucial for performance of the team of robots receiving the commands. Bipan et al [3] in their paper contributes by building a performance estimation model that explicitly investigates battery recovery problem in an Robotic mobile fulfillment system from both throughput time and cost aspects, with multiple recovery strategies. Adarshdave et al [4] demonstrated the first automated design of battery electrolytes by machine learning integrated into robotics which is important in the current context of battery research in mobile robots. Matsuda [5] et al investigated the improving the performance of the Li deposition/dissolution reaction which again becomes an important parameter investigation technique. Ren et al [6] reported the variations in the output voltage of the negative work harvesting mode energy module under different walking statuses which could act as a precursor for understanding the analysis of robotic system batteries. Xueqin et al[7] elaborated on the model of energy management strategy and it's optimization through his work.
This work is a test on the existing battery system on spark V robots with changes in the way the batteries are charged which is not found in the literature. There is work done on power management of robots but not specific to the group of robots that are under discussion in this paper.

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II. METHODOLOGY

A. Experiment 2 a: Discharge cycle testing based on installed beep

The procedure involved comparative analysis of two robots of same indigenous design with modification to their power management module. The robots in discussion are Spark V robot manufactured by Nex Robotics and Hindustan Dynamics and which have been procured for testing & training purpose for academic research purpose. A standard code for discharge based on discharge without motion and only based on usage of beeping duration until the battery completes died out was performed. The code was a standard test protocol that was developed indigenously with varying time periods.

The performance comparison for the two set of batteries on two different robots which were fully charged as specified in table 1. The equation governing NiMH proposed for mobile robot can be approximated as follows

$$V_t = 9 - 9 * DOD * N_C \qquad ....(1)$$

The equation takes into consideration the standard operating voltage of a rechargeable NiMH/NiCd battery installed on the casing of the spark robot. The DOD is the depth of discharge which is proportional to the full capacity rating of the battery and Nc is the standard rating of the number of cells that are present in the battery.

It is approximated that the differential change in the discharge against the voltage happens in terms of the usage of sensors, motors, beep mechanisms that are connected to the robot at a given instant which can be again approximated with an equation

$$\frac{dv}{dt} = k1 * \frac{dD}{dt} * N_C - n_1 * P_r - n_2 * T_r - n_3 * P_{bp} \qquad ...(2)$$

The two robots were modified in the base chassis for the power management module as shown in the figure below

Modified Power Capsule Original Power Capsule

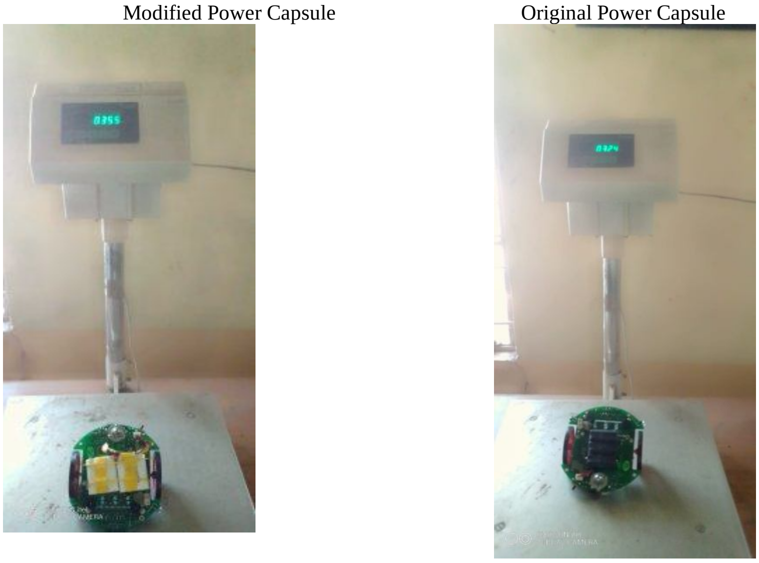


Figure 1: Comparison of modified and original Spark battery systems

The design would have to have a variation in discharge cycle which happens as per the equation 2 where we consider the discharge cycle, n1, n2 & n3 are the proportional constants with a linear approximation for the differential change, Pr and Pbp indicate the power rating of the motors and the beeper and the Tr indicates the time rate at which the sensor captures the details based on programming.

B. Experiment 1b: Discharge cycle testing based on random motion

As part of this experiment, the code for running the robot randomly forward, backward, turning around and rotating was loaded on both the robots which were fully charged and tested for the duration until the low battery indicator starts beeping up for both the robots. It was seen that NiCd battery module outperformed as discussed in tables 2 and 3.

TABLE I. ROBOT DESIGN MODIFICATIONS

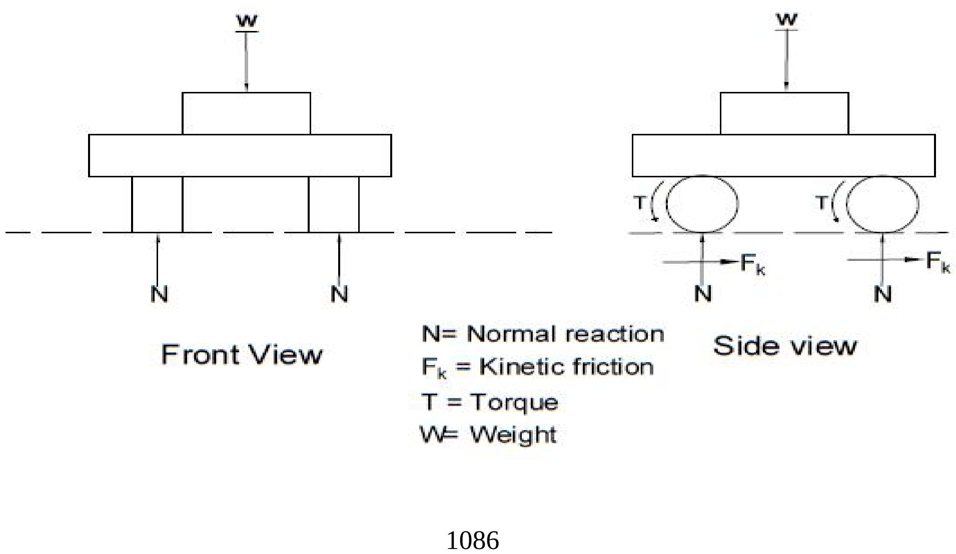
S.no	Weight(Kgs)	Battery Type	Battery Model Speficications	Original/Customized	Standard Charging Time	Robot Name
1	0.324	Manufacturer provided	NimH AAA HRO3, 60AAAHC, 1.2V. min 600mAh	Original	16 Hours at 50 Ma	Spark V
2	0.355	Customized with VIPOW Battery Rechargeable cordless phone battery NiCd	NiCd(2 packs)	Customized	-	Spark_GVP_Pwr_ver1

Some important technical of the robots are as follows
Effect of reduction in weight on reducing the power consumption:
Mass of device with new battery : Case1: m1= 0.324 kg
Mass of device with new battery : Case2: m2= 0.355 kg
Equations of motion according to D'Alemberts principle:
Horizontal component: $\sum Fx = ma_x$ (1)
- 2 F_k = ma_x ; $F_k = \mu_k$ N (coefficient of kinetic friction = μ_k)
Vertical component: $\sum Fy = 0$ (2)
Moment component: $\sum T = I\alpha$ (3)

MASS OF ROBOT WITH NEW BATTERY (m1= 0.324 kg)	MASS OF ROBOT WITH PREVIOUS BATTERY (m2= 0.355 kg)
W+2N = 0; N = -(W/2) = -(0.324*9.81/2) =-1.589 N I = $\frac{mr^2}{2}$ = (0.324*35^2)/2 = 1.53125 kg-mm^2 $F_k=\mu_k$ N = 0.4* (-1.589) = -0.6356 N $a = -\frac{2*0.6356}{0.324} = -3.923$ m/s^2 $\alpha = a/r$ = (-3.923/ 0.035) = 112.08 rad/ sec^2 2T = 2 * I α = (2* 0.00153125 * 112.08) T = 0.171625 N-m = 171.625 N-mm	W+2N = 0; N = -(W/2) = -(0.355*9.81/2) =-1.7413 N I = $\frac{mr^2}{2}$ = (0.355*35^2)/2 = 0.00217437 kg-m^2 $F_k=\mu_k$ N = 0.4* (-1.7413) = -0.6965 N $a = -\frac{2*0.6965}{0.355} = -3.924$ m/s^2 $\alpha = a/r$ = (-3.923/ 0.035) = 112.11 rad/ sec^2 2T = 2 * I α = (2*0.00217437 * 112.11) T = 0.24376 N-m = 243.76 N-mm

MASS OF ROBOT WITH NEW BATTERY (m1= 0.324 kg)	MASS OF ROBOT WITH PREVIOUS BATTERY (m2= 0.355 kg)
Torque required = 171.625 N-mm	**Torque required =**243.76 N-mm

Free body diagram



III. RESULTS

The first set of experiments resulted in the following conditions

TABLE II: EXPERIMENT 1A ON BEEP MANAGEMENT

Case ID	Experiment Run	Battery	Remarks
1	Beep Run	Manufacturer Specified	Low Battery Indication started after 40 Minutes from full charge Display off after 44 Minutes Warning LCD off after 48 Minutes and 46 Seconds Battery voltage after 59 Minutes and 14 seconds is 4.66 volts
2	Beep Run	Customized NiCd Battery	No automatic cutoff after charging,

TABLE III: EXPERIMENT 1B ON RANDOM MOTION

Case ID	Experiment Run	Battery	Remarks
1	Random free motion of robot with run code	NiCd Battery(Customized)	Low battery indicates after 36 minutes of full charge Display goes after 47 minutes Motion slowed and the robot stopped after 51 minutes
2	Random free motion of robot with run code	NiMH battery(Manufacturer specified)	Low battery indicates after 32 minutes of full charge Motion stopped after 35 minutes

IV. CONCLUSIONS

The NiCd batteries that were replaced for the power capsule of the robot were relatively new compared to the NiMH batteries that were placed on the Spark V mobile robot placed by the manufacturer which is atleast 5 years old. It is to be recollected that the usage of the rechargeable batteries would become debatable on aspects of recharge cycle, discharge cycles and also the frequency of run times. However, in this experiment the focus was on the power management when the batteries are fully charged, it appears like NiCd is performing well when compared to NiMH which might have been well tested.

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