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Design and Performance Evaluation of 4 Wheeled Omni Wheelchair with Reduced Slip and Vibration

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Abstract

Holonomic wheelchairs are being popular for their ability to move in constrained spaces due to their omnidirectional mobility. In this paper we have presented design and development of a 4 wheel driven omni wheelchair suited for indoor navigation with reduced wheel slippage and vibration. The design has been evaluated with wheel load measurement from current consumption and vibration measurement with a 3 axis accelerometer mounted on the chassis. From the result and analysis, it is evident that our proposed design shows less wheel slippage and vibration than existing designs. The system can find its application as an assistive aid for geriatric population or as a smart indoor mobility vehicle.

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Keywords: Omnidirectional whelchair; 3 axis joystick; Holonomic Control; Slip;

1. Introduction

Powered wheelchairs have been developed over the years for locomotion disabilities and for geriatric assistance. Smart electric wheelchairs are special class of powered wheelchairs, which are becoming a natural substitute of the conventional wheelchairs as an assitive device. Moreover, due to the ease of control, application specific human machine interface and smooth mobility, electric wheelchairs are becoming a popular indoor navigation vehicle. One of the first prototypes of smart wheelchair was proposed by Madarasz et.al[1] in 1986 which presented a wheelchair designed to transport a person to a desired room within an office building given only the destination room number. Since then, many such smart wheelchairs have been developed and few have been commercialized[2],[3]. Most of the developed smart wheelchairs are modification over existing commercially available powered wheelchairs with add on facility to enhance maneuverability, navigational intelligence and multi-modal control interfaces. To name a few, NavChair[4], Office wheelchair with high Maneuverability and Navigational Intelligence (OMNI)[5], Mobility Aid for elderly and disabled people (MAid)[6], Smart Power Assistance Module (SPAM)[7], TinMan[8], etc. provides controlled indoor navigation. Among the wheelchairs developed with omnidrive or omnidirectional mobility, the OMNI (Office

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Wheelchair for High Manoeuvrability and Navigational Intelligence for People with Severe Handicap) is a mecanum wheeled wheelchair developed for individuals with severe mental and physical disabilities. Another example of an omnidirectional wheelchair is iRW[9], which provides a telehealth system with easy-to-wear, non-invasive devices for real time vital sign monitoring and long-term health care management for the senior users, their family and caregivers.

In this paper we have presented design and development of a 4 wheel driven omni wheelchair with reduced wheel slippage and vibration. All the wheelchairs or indoor transporters with holonomic drive are developed with mecunum wheels or are a three wheeled omni platform. Mecunum wheels are inherently suitable for handling high load but its turn rate is slow compared to omni wheels. 4 wheel platform with omni wheels are difficult to design, mainly because of its unequal ground reaction force. If designed properly, 4 wheeled omni platform provides better performance than platform developed with mecunum wheels. We propose a unique wheelchair design with omni wheels and proper suspension mechanism to provide enhanced mobility in indoor environment. The design has been evaluated with wheel load measurement from current consumption and vibration measurement with a 3 axis accelerometer mounted on the chassis.

2. Methodology

2.1. Omnidirectional Wheelchair Platform Development

Omni directional wheelchairs[14,15,16] posses special maneuverability due to the omni wheels which allows translational as well as lateral mobility. Unlike differential or steering drive, omni drive systems does not possess holonomic constraints, allowing motion in both the body axis possible. Moreover, translational movement along any desired path can be combined with a rotation, so that the robot arrives to its destination at the correct angle[17], [18]. In order to achieve this, the wheel is built using smaller wheels attached along the periphery of the main wheel. Each wheel provides traction in the direction normal to the motor axis and parallel to the floor. The forces add up and provide a translational and a rotational motion for the robot.

Holonomic drive system is usually designed with mecanum wheels (4 wheeled configuration) and omni wheels (3 wheeled configuration). 4 wheeled omni driven wheelchair are not common, but if designed properly, 4 wheeled omni drive provides better traction force compared to mecanum while turning. Design of a 4 wheel driven Omni Wheel based platform needs special attention. Regardless the surface type, all four wheels should receive equal ground reaction force (GRF) or else there are chances of wheel slippage. A Omni wheelchair is designed to support 120 Kg including the platform's own weight and payload with proper suspension mechanism to provide equal GRF in all wheels.

Wheelchair design comprises designing of the motor wheel assembly, a suspension mechanism and a chasis with sufficient load bearing capacity. Fig.1 shows different parts of the omni wheelchair. Motor wheel assembly (Fig.1a) consists of a 'L' shaped part called 'Main L' which holds the dual omni wheels of 8 inch diameter and ball bearings. The upper side of the 'Main L' houses two slots for attachment of another smaller 'L' shaped mild steel part labeled as 'secondary L'. The 'secondary L' houses a pair of vertical slots which connects a motor attach plate. The motor (Buhler, 24V) is firmly affixed with the motor attach plate. The horizontal slot present in the 'Main L', vertical slot present in the 'secondary L' provides the ability to align the motor shaft co-axially with the wheel rotational axis. This minimizes jamming of the motor shaft due to misalignment or manufacturing defects. Finally, a flange is designed to couple the motor shaft to the dual omni wheels. This motor-wheel arrangement prevents the system weight to be transferred to the motor shaft as radial load. Four of such assemblies are connected to the platform chassis.

The next most important issue to consider is the suspension system to ensure equal ground reaction force on the four omni wheels. Suspension system has been designed using rear shock absorber. The hydraulic damping present in the shock absorber reduces the oscillation in the system. A pair of rear shock absorber is selected on the basis of required spring stiffness, travel length. Fig.1b shows the designed front motor-wheel assembly with suspension mechanism, attached with the chassis. The suspension mechanism is intentionally connected in the front motor-wheel assembly to maintain the symmetry. The chassis is designed with mild steel 'L' of 20 mm width and 3 mm thickness. Finite Element Analysis is done in SolidWorks to optimize the width of the material at the given load. The chassis measures 540 mm x 440 mm and is rectangular to accommodate the suspension mechanism in the front. In the suspension design, two 'U' shaped mild steel plates are used as 'Hold plates' and named as 'Upper Hold Plate' and

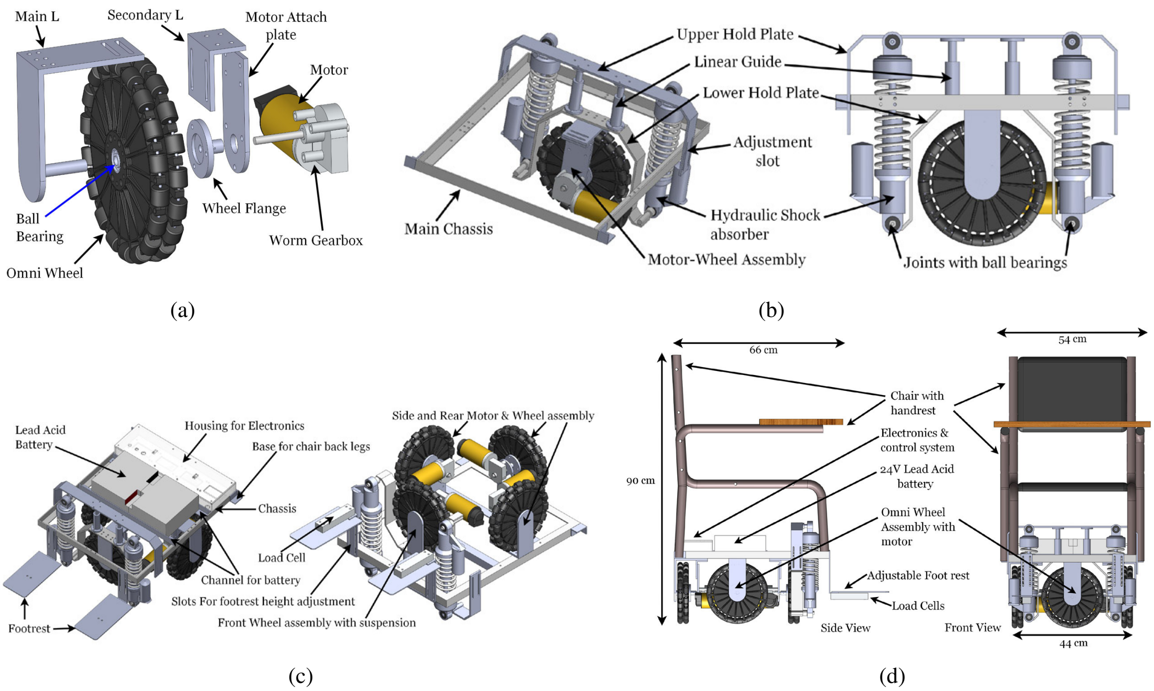


Fig. 1: Omni directional Wheelchair: a) Exploded view of motor-wheel assembly. b) Wheel arrangement and suspension mechanism. c) Wheel chair base d) CAD model of developed wheelchair.

Table 1: Wheelchair Specifications

Suspension		Omni Wheel		Motor		Wheel Chair	
Property	Value	Property	Value	Property	Value	Property	Value
Total length	250 mm	Diameter	8 inch	Weight	750 gm	Height	900 mm
Travel Length	50 mm	Type	Dual	Diameter	54 mm	Width	540 mm
Outer Diameter	55 mm	Weight	950 gm	Length	94 mm	Length	660 mm
Spring Stiffness	0.003N/m	Load Capacity	54.5 Kg	Rated Voltage	24 V	Width (base)	440 mm
Spring Type	Coil	Width	51.8 mm	Rated Power	77 W	Weight	20 Kg
Damper Shaft	Steel	Bore Diameter	28.5 mm	Rated Current	4.7 A	Payload (Max)	120 Kg
Weight	950 gm	No of Roller	36	Stall Torque	1.16 Nm		

'Lower Hold Plate'. The 'Upper Hold Plate' accommodates adjustment slots to adjust the suspension mechanism to work with a varied payload. The motor-wheel assembly is attached with the 'Lower Hold Plate' with 6 screws. Two linear guides are placed between the both hold plate to restrict the relative motion between them to only one axis. This arrangement prevents tilting of the front motor-wheel assembly with varied load conditions. Two shock absorber along with the two hold plates form a 4 bar system. With changing loads, the effective length of the shock absorbers would change. Thus the angle between the members of the 4 bar will also change. To accommodate this, the shock absorbers are connected with the hold plates as joints with ball bearings.

Fig.1c shows the view of the CAD model of the assembled omnidirectional robotic platform. Along with the front motor-wheel assembly mounted with suspension mechanism, the rear and the side motor-wheel assemblies are directly fixed with the chassis. The motors are positioned in the motor-wheel assembly horizontally with offset. In the

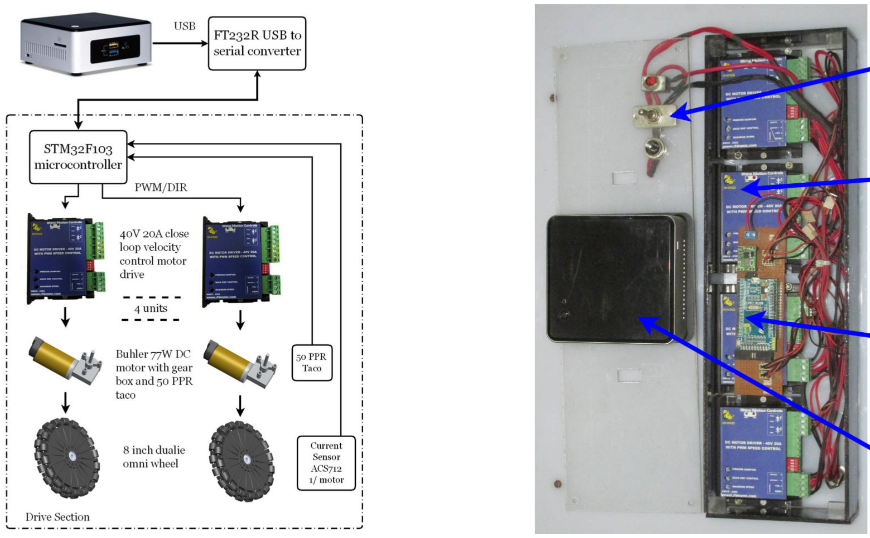


Fig. 2: a) Block diagram of the drive unit b) Snapshot of the motor drive unit.

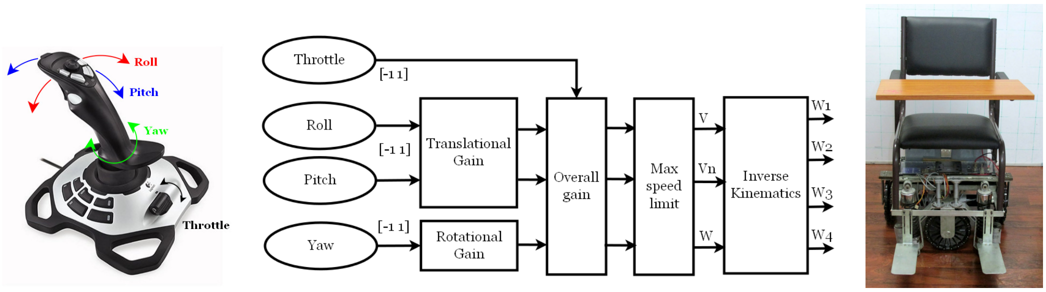
rear side of the platform, a housing for the electronics drive and controller made with acrylic fibre sheets is placed. All associated specifications for wheelchair development are tabulated in Table 1.

Electronic components of the wheelchair, shown in Fig.2 consists of four Buhler DC motors (77W) and their drivers (40V, 20A) from 'Rhino Motion Controls' to drive the motors. These motor drivers accept PWM/DIR input from the controller. The output velocity is proportional to the input PWM duty cycle. The driver measures the speed of the motor from current harmonics and regulates it by close loop PD control. The PWM/DIR inputs are connected to STM32F103, a 32 bit arm cortex M3 micro controller. All the PWM/DIR interface lines between microcontroller and the motor drivers are opto-isolated. 4 PWM channels of 'timer 1' of the microcontroller is connected to the 4 motor driver's PWM input. PWM resolution is kept as 2000 and frequency is kept as 50KHz. The motor drives also have current limit feature which restricts the start-up current to a user-set value. The Buhler motors are equipped with 50 CPR taco generator. These are connected with the 4 Input capture channels of timer 2 of the STM32 microcontroller. These enables the controller and the NUC to measure the actual RPM of the individual motors. ACS712-20A current sensor modules are connected with individual motors to monitor the current consumption. These sensors analog voltage outputs are connected to the analog input pins of STM32 microcontroller. Finally the STM32 microcontroller communicates with the master controller (NUC) via serial port. FT232R USB to serial converter is used to interface the serial port of the STM32 and USB port of the NUC. A MATLAB script running in the NUC generates the wheel velocities and sends to the STM32 microcontroller. The same script also monitors the actual velocity and current feedback from the motors through the STM32 microcontroller.

2.2. *Joystick control*

Joystick based wheelchair control is the popular control interfaces used conventionally [10-13]. Conventional control for wheelchair employs 2 axis joysticks, but as our developed system is a holonomic platform with 3 DoF mobility, it can not be controlled with conventional 2 axis joysticks. Logitec extreme 3D Pro joystick is used for controlling the wheelchair. As depicted in Fig.3a, this joystick has 4 analog inputs. One input is in the base, the other three analog inputs come from center large handle, which can be tilted forward, backward, left, right, as well as rotated clockwise, counter-clockwise. The forward-backward tilting is denoted as pitch control, left-right tilting is called roll control and the other is called yaw control.

The joystick is interfaced with the controlling NUC with USB interface. MATLAB provides ready to use library functions for acquiring the joystick data. MATLAB provided 'vrjoystick' is used to interface the joystick. All four axes returns a value between [-1 1]. For controlling the 3 DoF wheelchair, the pitch axis is mapped with forward-



(a) (b) (c)

Fig. 3: a) Logitech extreme 3D pro Joystick with the axis shown. b) Simplified block diagram of the joystick based control. c) Developed omni directional wheelchair

backward motion (robot translation velocity V), roll axis is mapped with left-right motion (robot translation velocity V_n) and yaw is mapped with the rotational motion (robot angular velocity ω). The analog values received from the joystick is mapped to robot velocities by multiplying with a gain factor. The gain for the translation velocities are kept same, but different for the rotation velocity. As the omni directional wheelchair can rotate while translate, it is important to keep the rotational gain separate from the translational gain. Higher rotational gain will cause instability (unwanted turning) of the wheelchair while going straight. Less value of the rotational gain will cause very slow turnings when desired. So independent adjustment of the rotational gain will provide user to user adaptability of the control system. A simplified schematic of the control scheme is depicted in the Fig.3b. The fourth axis of the joystick is also included in the control and plays an important role. All the values (V, V_n, ω) after gain multiplication, is again multiplied with the value coming from the throttle axis and is mapped into [0 1]. This increases the dynamic range of the joystick based control. While navigating in open space where greater velocity is required, user can keep the control to the maximum position. But while navigating in tight spaces, navigating through doors, when fine control of position is required, this control value can be kept low. This will enable the user to use the full range of the 3 axis handle to precisely navigate through tight spaces.

3. Result and Discussion

5 healthy male subjects were asked to control the wheelchair using conventional joystick control to traverse a predefined path. Fig.4 shows snapshot during wheelchair navigation and the traced path by 5 different subjects. Mechanical design of the system has been validated in terms of performance of the suspension-wheel mechanism. For 4 wheeled omni drive system, main design consideration is a proper suspension mechanism to distribute equal ground reaction force in all four wheels. Load on a particular wheel is estimated from the amount of current drawn by the particular motor. Current consumption in individual wheels is measured by the current sensor module (ACS712-20A) connected in series of the individual motors. The other issue to be considered is the vibration generated in the system. A 3 axis mems accelerometer ADXL 345 is mounted with the chassis of the system. To evaluate the performance of the system, a trajectory is fed into the system and current consumption and vibration data are recorded. This experiment is done without the suspension mechanism attached, and with the suspension mechanism attached. Fig.5a shows the figure of eight path traversed by the wheelchair during the experiment. Tracked path data has been calculated from odometry. Fig.5b and Fig.5c shows the generated velocity, current consumption in individual wheels and the 3 axis vibration data obtained from experiments without the suspension mechanism and with the suspension mechanism respectively. Table(2) lists the average values of the current and vibration data obtained during the experiment. The Z axis data of the accelerometer includes gravitational pull (+1g). From the graph and the tabular data, it is evident that the current drawn by the the individual motors are symmetric and follows the trajectory pattern. If any of the wheels had lost ground contact, the corresponding motor's current data had shown significant reduction. Now the graph also shows the nature of the vibration without and with the hydraulic suspension mechanism. From the table, it is evident that average vibration in all the axis has been reduced upto 50% after installing the new hydraulic suspension

mechanism. Also it is evident that due to reduced vibration, the current consumption of the system is also lowered by an amount of 15% with the improved design.

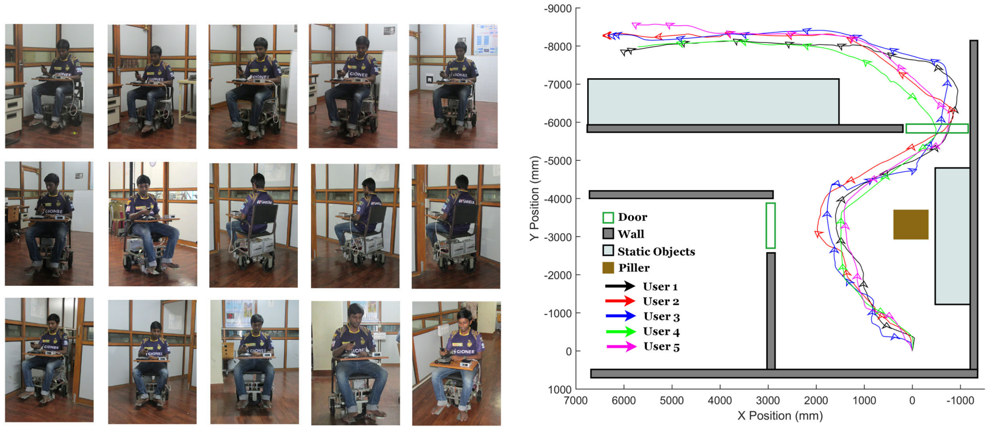
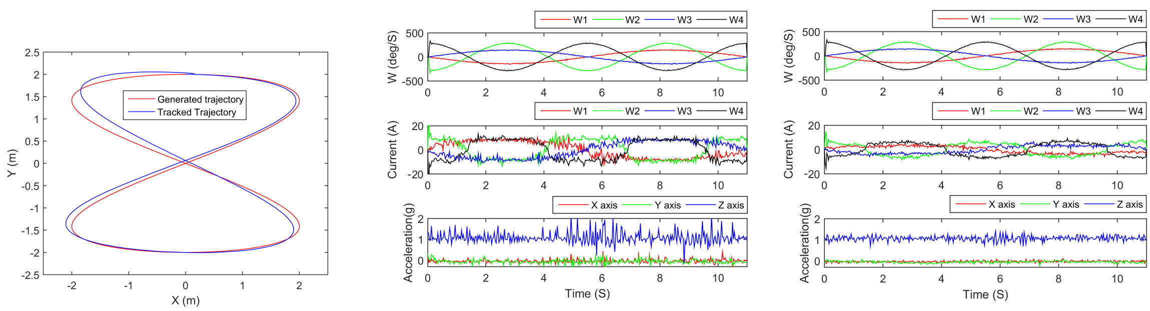


Fig. 4: a) Snapshots during a maneuver during a path traversal in a indoor environment. b) Path traced by the wheelchair for 5 different users.



(a) (b) (c)

Fig. 5: Stability analysis: a) Generated and tracked path b) and c) Wheel velocity, current and vibration data for experiments without suspension, with suspension mechanism

Table 2: Average values of the current and vibration data during the experiment.

	Current 1 (A)	Current 2 (A)	Current 3 (A)	Current 4 (A)	$Acceleration_X$ (g)	$Acceleration_Y$ (g)	$Acceleration_Z$ (g)
Without Suspension	8.633	10.375	8.541	10.414	0.093	0.106	1.091
With Suspension	7.021	9.478	7.883	9.339	0.059	0.066	1.057

4. Conclusions

In this paper we have presented design and development of a 4 wheel driven omni wheelchair with reduced wheel slippage and vibration. The design has been evaluated with wheel load measurement from current consumption and vibration measurement with a 3 axis accelerometer mounted on the chassis. Initial test results reported in this paper are based on 5 healthy users traversing a predefined path with static obstacle in controlled environment. In near future, the system will be tested for navigating in constrained environment with dynamic obstacles and its application as a rehabilitation aid or assistive system will be investigated.

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