Novel Omnidirectional Wheel Module

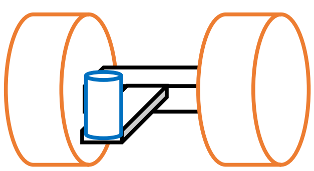
Nadine Wang Rei Ying

Introduction

Inspired by the simple swivel wheel, this is a novel prototype concept for a modular wheel module that can be easily adapted in any number for robot bases and other applications. Using Active Split Offset Castors (ASOC), the module can achieve instantaneous, omnidirectional movement via 3 independent degrees of freedom. The simple design has high power-efficiency and can carry high load capacities when compared to existing solutions for holonomic movement. This novel prototype concept, named the MBot-One, possesses unique advantages and capabilities, making it a promising, versatile solution for omnidirectional movement.

Concept and Kinematics of the MBot-One

Power castor wheels minimise scrubbing friction and instead rely on rolling friction to steer, by producing a moment about the rotating joint. Thus, less energy is loss as friction when the wheels are turned, making this design is highly power efficient. They can also support higher loads due to a more rigid build as compared to special wheels (e.g Mecanum, balls, or omniwheels)



Therefore, the main goals of the MBot-One design were to enhance the modularity and efficiency of power castors.

A simplified diagram of the MBot-One is shown in Figure 1. Using inverse kinematics, a relationship between the velocities of both wheels (orange) and the offset rotating joint (blue) can be established in a localised coordinate system XOY (Figure 2).

By controlling the inertial velocities of both wheels, arbitrary and unique velocities of the offset rotating joint can be achieved:

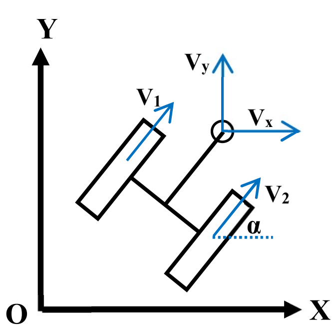


Figure 2: Velocities in a localised coordinate system

$$\boldsymbol{V_x} = \left(\frac{1}{2}cos\boldsymbol{\alpha} - \frac{S}{D}sin\boldsymbol{\alpha}\right)(\boldsymbol{V_1}) + \left(\frac{1}{2}cos\boldsymbol{\alpha} + \frac{S}{D}sin\boldsymbol{\alpha}\right)(\boldsymbol{V_2})$$

$$\boldsymbol{V_y} = \left(\frac{1}{2}sin\boldsymbol{\alpha} + \frac{S}{D}cos\boldsymbol{\alpha}\right)(\boldsymbol{V_1}) + \left(\frac{1}{2}sin\boldsymbol{\alpha} - \frac{S}{D}cos\boldsymbol{\alpha}\right)(\boldsymbol{V_2})$$

Full derivation of the kinematics can be found in Appendix A.

The key advantage of the MBot-One is that it is a *fully functional standalone module*. All the electronics, power supply and necessary encoders are self-contained as one robot. For every MBot-One unit, there are two controllable degrees-of-freedom (the two wheels which can receive unique velocity commands), and actual rotational position is received. Hence, any number of units (minimum two) can be used to enable the omnidirectional motion for any unique application. Thus, just a minimum of four simple velocity commands is required to achieve instantaneous, holonomic drive.

<u>Design and Components</u>

The overall build for the MBot-One is shown in Figure 3 below. Assembly only requires metric screws and nuts. (Link to models: https://bit.ly/2Zc6G6z)

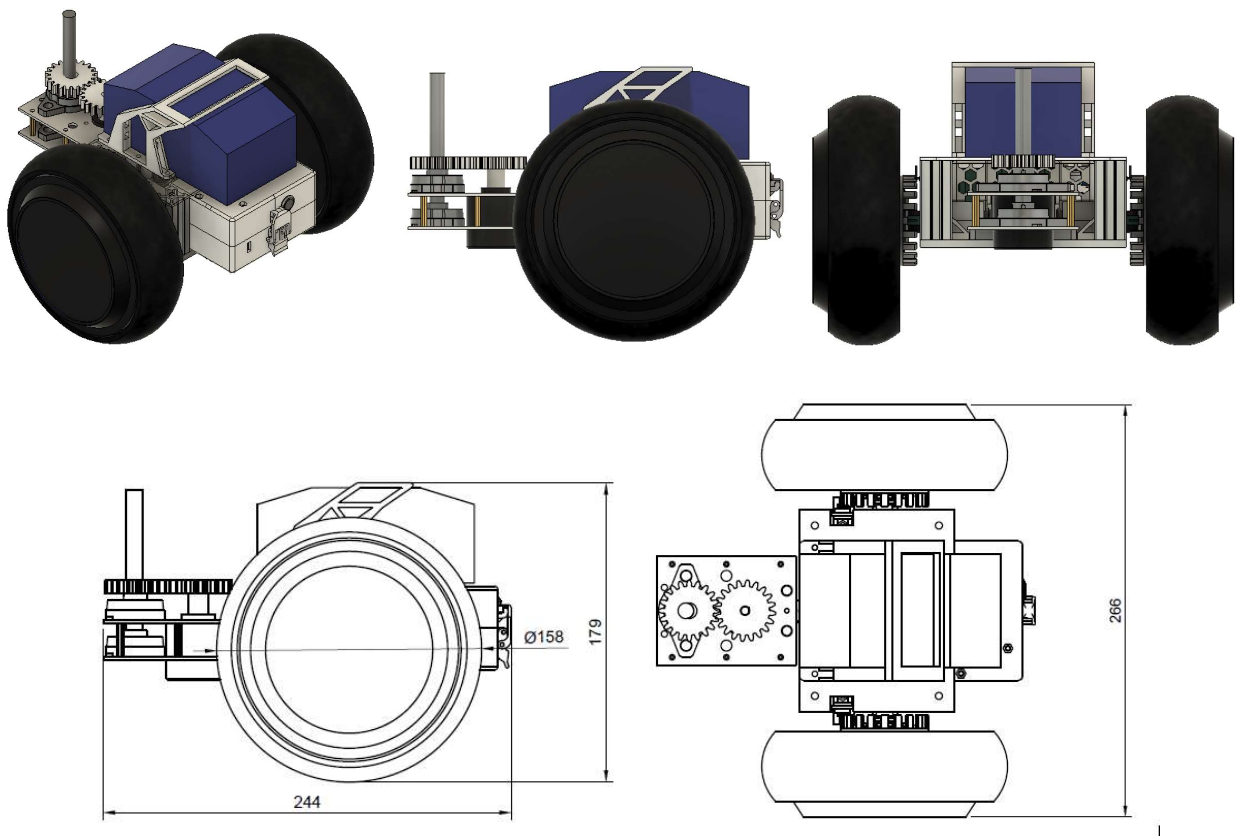


Figure 3: Design drawings and 3D model

1. Main Chassis

The main chassis comprises of the robot frame and motors. Parts sources and details can be found in Appendix B.

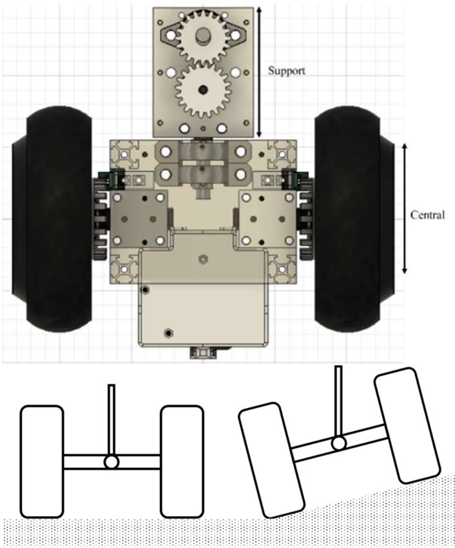


Figure 4a): Top view of main chassis, 4b) Passive suspension with free bearing

a. Central Section

Two brushless DC (BLDC) motors are mounted coaxially to the main plate. BLDC motors provide the advantage of direct drive to the wheels, compared to complex gearing for traditional motors. Two bearings allow the central section to rotate independently from the support section. This passive joint allows MBot-One to maintain traction on uneven ground, providing stability and reliable motion.

b. Support Section

Two FL000 pillow bearings create a revolute joint to allow the pivoting rod to rotate independently from the base of the support section. The rotation of this joint is measured by an absolute encoder. Gears were 3D printed to translate the motion from the joint to the encoder.

2. Electronics

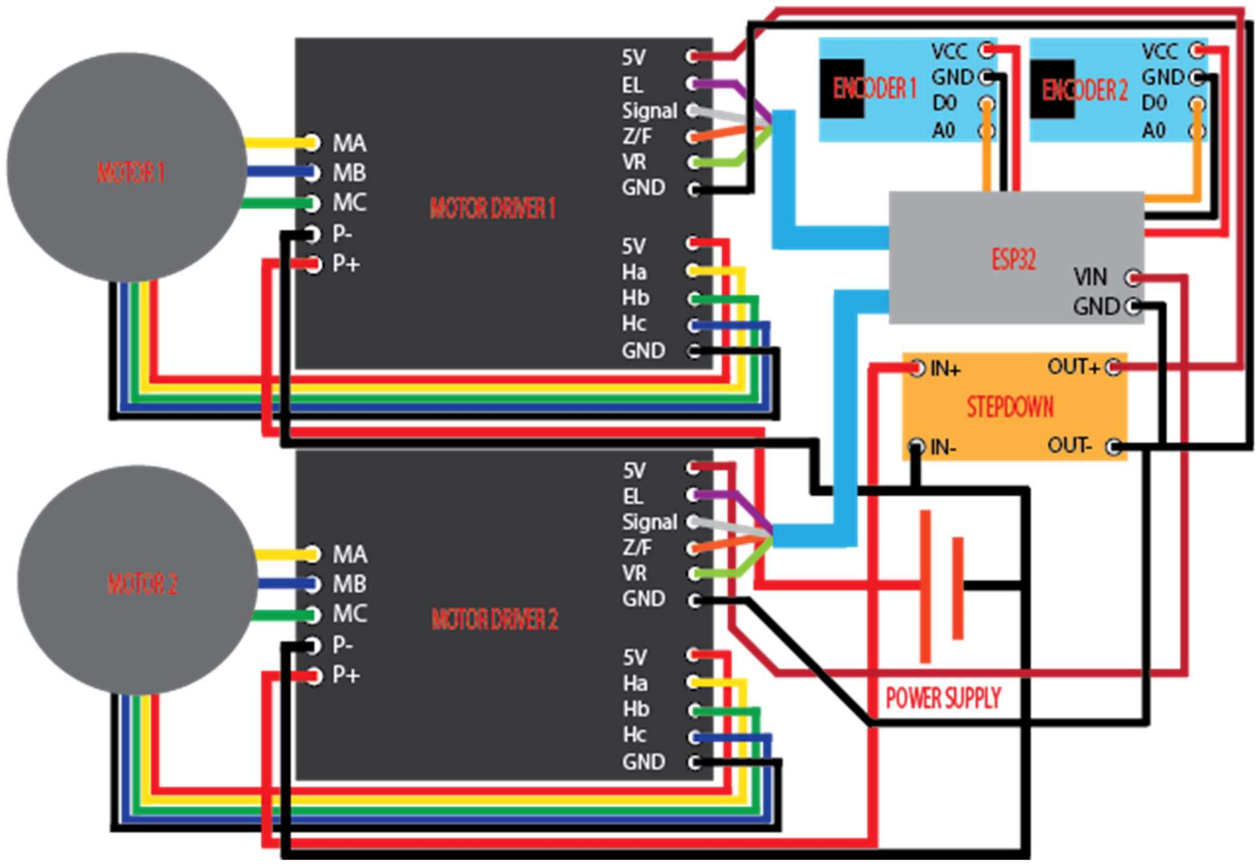


Figure 5: Electronics connections diagram

MBot-One uses one ESP32 module, two BLDC motor drivers, two infra-red encoders, and one absolute rotary encoder. They are wired according to the diagram above. Note that the order of coloured wires for MA/MB/MC will vary for different brands of motors; this also holds true for the hall output wires. The infra-red encoders are powered by 3.3V from the ESP32 to prevent noisy interrupt signals, which tends to occur for 5V V_{CC}.

The BLDC motor drivers have individual control pins for enable (EL), direction (Z/F) and speed of the motors (VR). An input signal pin receives the number of steps moved by the motor, measured by hall encoders inside the wheel. A pulse width modulation (PWM) signal is used to control the speed of the motor. All hall connectors must be connected for the wheel to work properly.

Not pictured in the diagram is a small screw terminal block for 36V and 5V lines to be shared in parallel with the various components. The absolute encoder is also not connected in this diagram. Parts source and details are noted in Appendix C.

Software

The wheels are controlled by a PI feedback loop to ensure consistent speed. The optical encoders measure the number of pulses per second, then send it to the ESP32 which modulates the wheel speed.

Codes can be found here: https://github.com/doonotfindmeplease/MBot-One

Future

The MBot-One is a compact, independent omnidirectional wheel module. The ability to operate locally with its own set of electronics and battery gives MBot-One a novel modularity. Thus, this is simply the first step towards being integrated into a distributive control system.

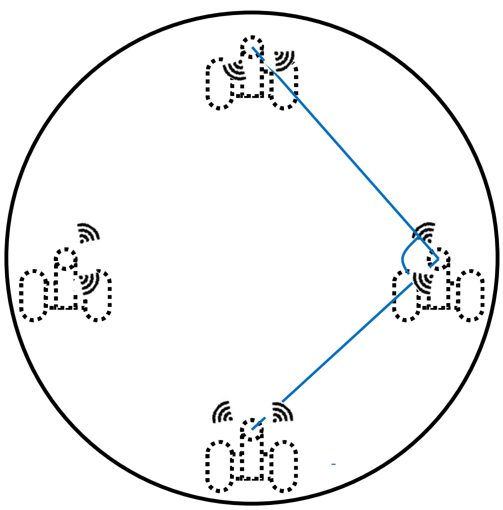


Figure 6: Arrangement of multiple MBot-One units for synchronised movement

Only a minimum of 2 MBot-One modules are required to achieve 4 independent DOF. Since the V_1, V_2 and trajectory of each MBot-One module relates to their distance and bearing from one another, it is possible to compute the desired V_1 and V_2 velocities of each module to allow the synchronised movement of all modules in a desired path. Thus, multiple MBot-One units can be arranged and synchronised together in any configuration to act as one omnidirectional system. Together with a self-calibration mechanism and wireless communication, the MBot-One modules would unlock a vast spectrum of applications by enabling the omnidirectional mobility of many systems.

Appendix A

For a split offset castor with 2 coaxial wheels separated by distance D, and connected to an offset joint of distance S, a localised coordinate system XOY (Figure A.2) is defined.

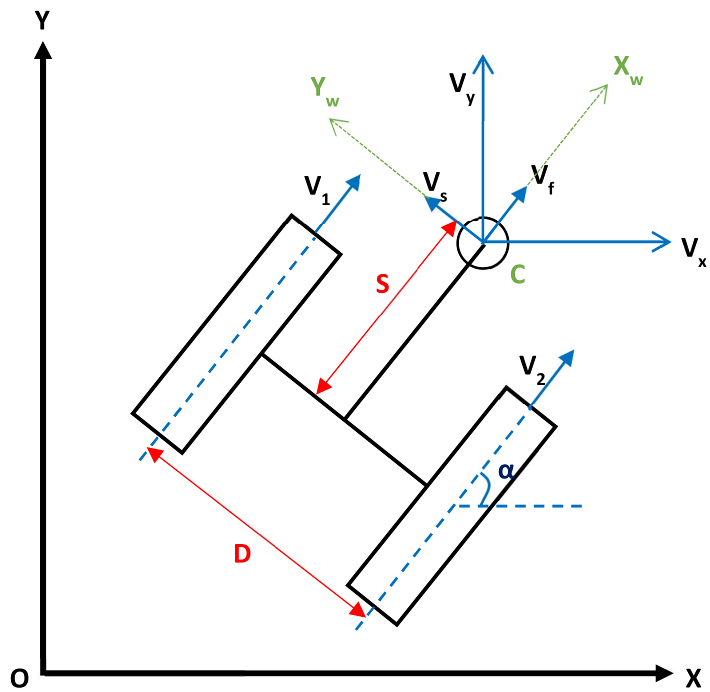


Figure A.2: Coordinate system and MBot-One kinematics

Wheel velocities are V_1 and V_2, and joint velocities with respect to ground are V_f and V_s. The two vectors **u** and $\mathbf{q_w}$ are defined as:

$$\boldsymbol{u} = [V1 \quad V2]^T$$

$$\dot{\boldsymbol{q}}_{\boldsymbol{w}} = [Vf \quad Vs]^T$$

From there, the Jacobian matrix of the ASOC module in the moving coordinate frame XwCYw is $\mathbf{J_w}$, where $\mathbf{q_w} = \mathbf{J_w}\ \mathbf{u}$:

$$\boldsymbol{J_w} = \begin{bmatrix} 1/2 & 1/2 \\ S/D & S/D \end{bmatrix}$$

The velocity of the joint in the inertial frame **q** is given by:

$$\boldsymbol{q} = [Vx \quad Vy]^T = \boldsymbol{R}\dot{\boldsymbol{q}}_{\boldsymbol{w}} = \begin{bmatrix} \boldsymbol{cos\ \alpha} & \boldsymbol{-sin\alpha} \\ \boldsymbol{sin\alpha} & \boldsymbol{cos\alpha} \end{bmatrix} \dot{\boldsymbol{q}}_{\boldsymbol{w}}$$

where **α** is the orientation of the ASOC module with respect to the X axis in XOY.

The kinematic relationship between the inertial velocity of the joint and the two wheel velocities is:

$$\dot{\boldsymbol{q}} = \boldsymbol{R}\dot{\boldsymbol{q}}_{\boldsymbol{w}}\boldsymbol{u} = \boldsymbol{J}\boldsymbol{u}$$

where **J** is the Jacobian matrix for the ASOC module in XOY:

$$J = \begin{bmatrix} \boldsymbol{1/2cos\alpha - S/Dsin\alpha} & \boldsymbol{1/2cos\alpha + S/Dsin\alpha} \\ \boldsymbol{1/2sin\alpha + S/Dcos\alpha} & \boldsymbol{1/2sin\alpha - S/Dcos\alpha} \end{bmatrix}$$

The determinant of **J** is therefore:

$$det\, J = -S/D$$

Appendix B

Parts/ Qty	**Source**	**Est. Cost (S$)**
BLDC motors, 6.5 inch (2)	Taobao	120
Ball bearings, P000 and FL000 (4)	Aliexpress (Shenzhen Feijia Electronics-Tech Co., Ltd.)	9
Aluminium T-slot extrusions, 2*2*5cm (4)	-	2
M3 copper standoffs, 3cm (6)	Aliexpress (SCREWHOME Store)	2
Assorted CNC parts, Al 6061	-	-
Laser-cut acrylic top plate	-	-
Steel rods (Aluminium rods are also suitable)	Aliexpress (Tianshihong-Tech Store)	8
Assorted metric nuts and bolts	-	-
3D-printed parts: - Encoder discs (2) - Gears (2) - Driver mounts - Encoder mounts - Battery mount - Electronics housing	-	-
	Total	141

Appendix C

Parts/ Qty	**Source**	**Est. Cost (S$)**
ESP32 Devkit V1 (1)	-	8
BLDC motor drivers (2)	Lazada (run2top)	32
FC-03 LM393 infrared encoders (2)	Lazada (Areyourshop)	2
Absolute encoder single-turn SSI CAN RS485 (1)	Aliexpress (BriterEncoder)	37
DC-DC LM2596 buck converter (1)	Lazada (Clarify)	1
	Total	80