Mecanum—we can't even agree on pronunciation?(rev3)

FRC Team 1361 – Nightmare Robotics

Special thanks to Ether for contributions and inspiration for the paper in the first place

Mecanum wheels are insane. Because they are so different from our everyday experience, they have created A LOT of misconceptions. Here we attempt to look at the physics of driving both regular and mecanum wheels while investigating some of these misconceptions.

Note: There is a lot of other information available on mecanum, so the general information here will be very brief.

What is Holonomic Drive?

Holonomic drive, in the realm of robotics, refers to the ability to move in any direction and rotate independently. This drive allows you to pick any direction and move that way without needing to first rotate to that direction. There are multiple types of holonomic drive: omni, kiwi, Killough, and Mecanum are some examples.

How normal wheels work:

You have an input torque which the wheel translates to a force it applies to the ground (Input torque / wheel radius = Force applied) Newton's 3rd law says that that this force has a pair which is equal in magnitude and opposite in direction; i.e. the wheel pushes the ground backwards, the ground pushes forward on the wheel. This will be looked at in more depth in misconception 2.

How mecanum wheels work:

Mecanum wheels translate torque to an applied force on the ground at an angle of 45 degrees to the plane of the wheel. This is what makes them so weird (different even from an omni wheel) and why strafing (moving sideways relative to the plane of the wheels) looks almost spooky the first time you see it.

This video shows how the turning of a mecanum wheel translates into a force which is 45 degrees from the plane of the wheel.

(insert video – wheel pushes paper out 45 degrees)

4 mecanum wheels can allow holonomic drive. This can be seen by resolving the force vector of each wheel into forward/sideways components, then looking at how they combine with the forces from the other wheels as you use different permutations of wheel rotation direction. Note: The "real world" vector here is at 45 degrees. It makes analysis easier to resolve this vector into components.

(insert components picture)

*some of the thought experiments and caveats—not any of the silly stuff…

Mecanum Misconceptions – a.k.a. Trying to prove the existence of Ether

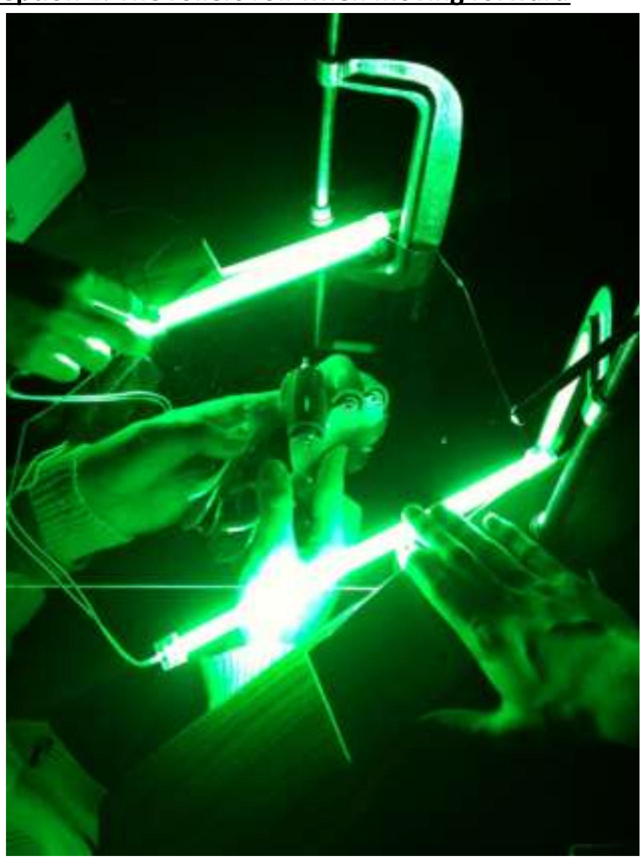
Our team first tried mecanum in 2011 for logomotion, and we noticed there is A LOT of disagreement and misconceptions all over www.chiefdelphi.com about mecanum. Ether has posted some great whitepapers on the topic… http://www.chiefdelphi.com/media/papers/2390

…and has *tried* to battle misconceptions as they pop up in different posts; however, it appears to us that Ether is correct but still very much in the minority. Our team tried to work through some of them and we also struggled because the physics involved is not exactly intuitive and people make really good arguments on both sides. So, in an effort to improve knowledge of one of the most popular drives in robotics, we've decided to post a whitepaper and hopefully get some consensus on many of these points. We think it's sad to think that many teams might never try this very fun drivetrain based on misinformation.

We are approaching this section by using a fictional voice with contrary viewpoint. We hope that it serves as a way to better present some ideas. We also would like to stress that we've put some of these quotes in not as an attack for those that share them as being foolish, but quite the opposite: We felt some points were so well stated and supported that the only way to address them was in this manner.

Again, most of this was covered by Ether. We're just re-organizing it, adding to it, and taking a few points a bit further.

Misconception 1: The rollers roll when moving forward



We set up a test to look at 2 things: 1) what the contact point of the rollers on the ground looks like while moving and 2) whether the rollers roll when moving forward. We utilized the phenomenon of FTIR: Frustrated Total Internal Reflection to highlight the contact point of the rollers. A piece of polycarbonate was placed across 2 tables with a couple lights placed on their edge. This creates a lot of light passing through the polycarbonate via TIR. When the roller comes into contact it "frustrates" the TIR which causes light to be scattered from that point and essentially makes it look lit up.

We then rolled the wheel by holding it tight against the poly and applying torque while pulling the wheel toward us and allowing the friction to pull back—basically recreating the driving situation. We did NOT just roll the wheel along. This is hard and takes some practice…

And yes, all the rollers CAN freely spin. We are a bit obsessive about them actually.

Here is the link to videos of this: http://vimeo.com/32952134 http://vimeo.com/32952366

Misconception 2: Mecanum has less power/torque

Quotes from CD:

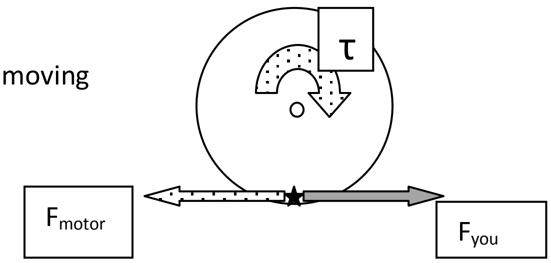
- "As for mecanum, there is always a question as to the loss of power vs. maneuverability issue"
- "Only ~71% of the output torque is transmitted in the direction of travel"
- "So when you input a speed to go forward, you lose efficiency in that you are transmitting power in a direction that you aren't heading in."
- or 5,085 other quotes I could have chosen

At its root, this argument states that for a given input torque, a mecanum wheel has a smaller force applied to the floor in the plane of the wheel than an identical sized regular wheel.

Static Condition

This misconception is most easily dealt with by looking at a static condition (not moving). So, here are the conditions:

- 8" wheel
- 40in-lbs of torque applied from a motor via the axle
- The axle is free to spin, but otherwise cannot move
- A star is attached at the edge that you push to keep the wheel from moving



(FYI – Torque is the angular version of force. Torque = Force * radius)

a) If the motor applies 40in-lbs of torque, then the star at the very edge feels a force: F=40in-lbs/4in = 10 lbs

b) If the motor applies torque, the associated force on the edge of the wheel is pointing **in the plane of the wheel** (note: we are NOT looking at the force the wheel puts on the ground-THAT is the force for which mecanum will be at an angle. This is the force the motor is putting on this particular bit of the wheel)

c) If you keep the wheel from spinning, then the force you apply must be **equal and opposite** the force due to the motor

d) If your applied force is equal and opposite, then it is 10lbs pointing in the plane of the wheel.

Note that this means the net force on this point of the wheel will always be zero, unless you can't handle the force the motor is applying. This is what is supposed to happen. If you take a snapshot of any wheel being driven without slipping, everything here stays the same except the force you applied on the wheel is now being applied by friction from the floor. That's why STATIC friction is always talked about with wheels: the piece of wheel in contact with the ground isn't moving.

Here is a link to a nice GIF of this

"If net force is zero, then how does the wheel ever move forward?" That particular part of the wheel had zero net force. The force of you (or the ground) on the wheel is transmitted via the structure of the wheel to the axle. The force on the wheel at the axle due to the motor is zero, so the NET force on the axle is forward!

Note that this example holds whether you are talking about mecanum or a regular wheel. This is due to the fact that the forces in question are on the wheel. The wheels differ in how they transmit this force to the ground, and this is where there are 2 camps that diverge. Take the same case as above, but now we are talking about an 8" mecanum wheel on the ground, and it is friction keeping the wheel from spinning.

Team Ether: (FYI-we already trademarked this term for t-shirts)
The 10 lb force on the edge of the wheel due to the motor is transmitted to the ground as is. The wheel applies a 10 lb force on the ground in the plane of the wheel in a backwards direction. Since the wheel applies a force at 45 degrees, this force must be 10√2 lbs at an angle of 45 degrees to have a 10 lb component backwards.

In the plane of the wheel:

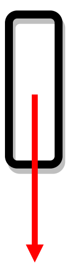
$$F_{\text{motor on wheel edge}} = F_{\text{wheel on ground}} = -F_{\text{ground on wheel edge}}, \text{ so } F_{\text{net on wheel edge}}=0$$

Team other:
The 10 lb force on the edge of the wheel due to the motor is transmitted to the ground at a 45 degree angle; therefore, the component of this force that is parallel to the wheel is only ~71% or 5√2 lbs.

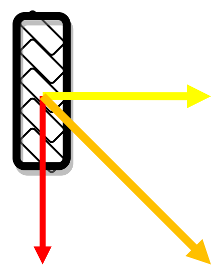
In the plane of the wheel:

$$F_{\text{motor on wheel}}=10\text{ lbs}, \quad F_{\text{wheel on ground}} = -F_{\text{ground on wheel}} = 5\sqrt{2}\text{ lbs},$$

$F_{\text{net on wheel edge}}$ **IS NOT ZERO. Remember the condition is a static wheel, so Fnet must be zero. Therefore, the premise must be false.**



Regular wheel
10 lb force



Mecanum Wheel
10√2 lb force
10 lb component equivalent to regular wheel
(bird's eye view showing bottom rollers only)

"This means that a mecanum wheel creates MORE force than the same size regular wheel. This makes no sense; you could even have your motor power a mecanum, then have a regular wheel make contact below and at a 45 degree angle. Since they are the same diameter wheel you get more torque at the same angular speed which equals more power."

A thought experiment so cool (and persuasive), we had to make it a real experiment: http://vimeo.com/33315586

You can see from the video that the regular wheel actually is spinning slower than the mecanum wheel, so torque/force increases, speed decreases, power stays the same—just as when using gears, pulleys, etc.
There is another aspect of mecanum that is very different from a regular wheel: pi does not always apply**. The circumference of a mecanum wheel is not always equal to pi times diameter. In the case of doing a simple calculation of distance traveled per wheel revolution you would have an "effective" circumference according to pi***. In this thought experiment above, the circumference is closer to the total length of all rollers*. If you go back to the FTIR video you can see how the point of contact of the wheel follows the length of the rollers

*it's actually more complicated, because the roller has to roll slightly as it moves across the width of the regular wheel , so the contact point doesn't follow just the elliptical of the roller edge.

**FYI we also trademarked the phrase: "Mr. Mecanum is skinny. He doesn't always accept pi."'

***The actual circumference is the elliptical roller length totals, but the speed the contact point travels is faster than that of the analogue for a regular wheel, so they cancel to give you a "regular" effective circumference

Dynamic Condition (forward and reverse)
If you also take into consideration that when traveling forward and backward the rollers DON'T roll – then the forces in the static case discussed above applies when you travel in those directions. The torque from the motor translates to 100% of the expected force you would get with a regular wheel.

<u>Caveat 1:</u> Axial free-play in the rollers can cause the rollers to spin somewhat even when driving straight forward. As each roller is pushed through the free play as it contacts the floor, it rotates.

<u>Caveat 2:</u> Compliance in the floor surface (e.g. carpet) can cause the rollers to spin somewhat even when driving straight forward. As the roller's contact point with the floor travels along the roller's length (as shown in your video), the fibers of the carpet are pushed back in the direction of the roller's axis. This fakes the roller into thinking it has a sideways component of motion, and so it rotates accordingly.

*You can add caveat 1&2 together and it doesn't make a significant (for FRC) effect. Certainly not enough to tell mecanum newbies that mecanum has an "inherent loss of power". (no data to back this statement up currently-coming ~~soon~~ sometime)

Misconception 3: Mecanum lacks "pushing power"
This phrase is commonly used with 3 different meanings:

Misconception 3a: 29% of torque is "wasted" as sideways force components
this is just misconception 2 discussed above

Misconception 3b: You can't push something if your rollers just roll from underneath you
this is just misconception 1 discussed above

~~Mis~~conception 3c: All other things equal, mecanum loses to regular drivetrain in a pushing contest
This is true. 2 robots: Mec and Reg are identical for every detail except Mec has Mecanum wheels and Reg uses Regular wheels. If both are pushing against a force sensor fixed to a brick wall and slowly ramp up their motor's output torque. Both robot's force sensors will be equal and ramp up at the same rate; however, Mec's wheels will slip before Reg. this is because driving relies on static friction to work under normal circumstances:

$$F_{friction(max)} = \mu\, F_{normal}$$

Since both robots have the same weight, and use the same wheel tread material, they have the same maximum value for static friction. However, from an earlier discussion we learned that Mec's wheels will have a force component in the plane of the wheel equal to Reg's . In order to do so, the force on the diagonal is larger by a factor of square root of 2. This means that while both robots translate equal force in the plane of the wheel, Mec's wheels are translating MORE total force to do so, and therefore will reach the maximum static friction first.
(insert force graphs)

Misconception 4: Mecanum is complicated and inexperienced teams should not attempt it in season

If we can do it – anyone can. We're starting to wonder if the name Nightmare Robotics is becoming ironic…

Misconception 5: There is a verified correct pronunciation of mecanum.

We have yet to discover anyone who has firsthand knowledge of the pronunciation used by the inventor. therefore we are going with mee-KAY-new-OHM. (not really… We say MEH-cuh-num only due to guessing and now tradition, but we hear Andy Baker (who sold us the wheels) says meh-CAN-uhm, so we're trying to conform to that…)
<u>update:</u> [Swedish Pronunciation Guide]