# Design and Test of a Tracked Personal Transportation Device

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*Abstract*— **A *rideable* is a small, portable, electric vehicle used to transport an individual in an urban environment. This new class of electric vehicles are perfect for the urban commuter and are rapidly growing in popularity. This is particularly evident from the rapid rise of electric scooter rental companies. However, many available rideables have a number of disadvantages that may be curbing their growth. This has created an opening in the market for a new rideable, that excels in areas where current rideables have shortcomings. This paper presents a new rideable, the *TracPerT*, which, uniquely, uses tank style tracks rather than conventional wheels for traction and locomotion. This new rideable is designed to deal with the difficulties presented by currently available personal transport devices. Progress on the first powered prototype of the TracPerT is reported.**

## I. INTRODUCTION

Personal Electric Vehicles (PEV) emerged as a new category of transportation device in the late 1990s [1]. Rideables are a new category of small, light PEVs, such as electric skateboards, scooters and unicycles. This newly emerging class of personal electric vehicles are becoming increasingly popular in today's smart cities.

Historically, rideables struggled to become popular due to three main factors, as highlighted in [1]: their weight, cost and range. However, more recent publication [2] contend that each of these issues has now been addresses. In recent years, batteries have become increasingly affordable and energy-dense [3]. Power electronics for motor control, such as the Vedder Electronic Speed Controller (VESC) [4] have become more accessible and the corresponding motors have become sufficiently compact, powerful and affordable. All three of these factors contribute to creating lighter, cheaper vehicles that have a much higher range and power than was previously possible. It is clear that their increasing efficiency has led to their growing popularity.

Also contributing to this is the trend towards pedestrianization of city streets and the increasing proliferation of bike lane infrastructure. Many governments seek to improve mobility in city centres as a form of urban renewal and for sustainability [5]. The effect of this is evident in [6], where street renovations in Tel Aviv resulted in a significant increase in rideable usage.

Another important trend in personal urban mobility is the emergence of bike-sharing schemes, which are increasing in popularity as governments attempt to reduce car usage in city centres. As a result, considerable research has been undertaken to optimize and improve current bike-sharing schemes [7], [8], [9], [10]. Recently, there has been a notable emergence of well-capitalised scooter rental companies such as *Bird* and *Lime*, who are transforming city centre mobility: *"Some scooter firms are already unicorns privately held companies valued at more than $1 billion"* [11]

These sharing schemes contribute to reducing the carbon footprint of cities as the public opt to use these electric vehicles over diesel or petrol powered forms of transport, and in synergy with existing public transport offering. As a result, it is likely that these schemes will continue to grow in popularity with increasing government support [12].

One of the main problems identified for rideables was highlighted in [13], which noted that confusion exists about where such vehicels are allowed to travel. Reference [11] also discusses this problem, specifically referring to electric scooters; *"Some riders claim the sidewalk; others ride in the street. Some will follow pedestrian signals, some will obey traffic lights, and some will do none of the above."* This is due to a lack of laws for the emerging technology. This has been evident with the growth of electric scooter rental companies such as *Bird* and *Lime*, where their advancement has been banned or limited in certain American states due to the rapid, mass introduction of the unregulated scooters. However, as popularity continues to increase, changes in laws and legislation are an inevitable outcome, and this effect is already being seen.

The TracPerT (*Tra*cked *Per*sonal *T*ransporter)is a new form of personal vehicle, designed to hybridise the merits of existing rideables. The concept for the TracPerT was originally proposed in 2017 for the *"UCD Engineering Mobility Research Competition"* [14] by one of the present authors and Mr. Milo Cuffe. In order to improve on existing rideables, the design uses rugged tank style tracks instead of wheels. This concept emphasises stability, ease-of-use and portability. The use of tracks should allows the device to be mobile and stable across all terrains, not just flat paved surfaces. The tracks are raised at the front allowing the rideable to easily move over bumps and cracks and to mount curbcuts and other level-changes. The design is for a light (<10kg) and small vehicle, allowing it to be easily carried when necessary, and to be used in conjunction with other transport modes.

The objective of this paper is to discuss popular available rideables and present the features and design of the first powered prototype of a tracked personal transportation device, the *TracPerT*.

## II. EXISTING RIDEABLES

There are a number of advantages to rideable use in the modern, smart city. In particular, rideables are capable of extending the travel range available to people living in urban environments. Pedestrian travel times and short car trips can be drastically reduced with rideables. As outlined in [1], a 5km car journey in an urban area can take 30 minutes. This same trip could take 50 minutes to walk or just 12 minutes by rideable.

Combining rideables with other forms of transport can vastly increase the ease, speed and range of travel for commuters. Discussed in [15], cities such as San Francisco and Bat Yam have tested automated systems that vary parking prices to suit demand. Systems such as this mean that parking on the outskirts of cities will be much easier and more affordable than city centres. This encourages commuters to avail of public transport or other means of travel, such as rideables. Seen as a first or last mile vehicle, rideables are ideal in this role. Additionally, many rideables are well-suited for intermodal commuting, being portable enough to easily be brought onto buses or trains, even during peak travel times. This opens up access for commuters living in poorly serviced areas with limited and distant public transport.

Another advantage of rideables is that they are cost efficient. Work in [2] was estimated that approximately 38,000 commuters in Dublin would benefit by using rideables. Assuming that a rideable could save a commuter just 10 minutes on each leg of their journey, they would save approximately €801 per year in travel time, if only working a minimum wage job [2].

According to a study in 2017 by the US Department of Transportation [16] approximately 60% of all vehicle trips were less than six miles. With cheap rideables, easily capable of a 6mile (∼10km) range available [17], many of these trips could be replaced. This would reduce traffic and carbon emissions, replacing motor vehicles with cheap, green, electric-powered rideables.

However, as with many new technologies, there are problems when introduced into an unprepared world. Streets and footpaths in many cities are often unkept and worn, consisting of cracks and potholes. Bumpy cobblestone streets and worn stone squares are also common in old cities and towns. Neither of these are ideal for many existing rideables as their small wheels can easily catch in the bumps or cracks, creating an uncomfortable and bumpy ride. In contrast, street renovations in Tel Aviv [6] resulted in large paved boulevards perfect for travelling through on *"the ubiquitous electric rideables of every kind that have taken over the city."* This shows that given a suitable environment for use, these rideables can easily become popularised.

TABLE I: Summary of Ridables Relative Strengths

| | Electric Skateboards | Electric Scooters | Electric Unicycles | Tracked Personal Transporter |
|---|---|---|---|---|
| Ease-of-Use: | ✗ | ✓ | ✗ | ✓ |
| Portability: | ✓ | ✗ | ✓ | ✓ |
| Terrain Versatility: | ✗ | ✗ | ✓ | ✓ |
| Manoeuvrability: | ✗ | ✗ | ✓ | ✓ |
| Stability: | ✗ | ✓ | ✗ | ✓ |

### A. *Skateboards*

Electric skateboards first became popularised in 2012, largely through the company *Boosted*. Driven by one, two or four powerful brushless DC (BLDC) motors, they can be belt driven or hub driven (where the motor is integrated as part of the wheel) [18]. Most are controlled with a handheld controller, however, some are controlled with foot pressure sensors [19]. As their popularity has increased, many new companies have created competition in the market, creating diversity and encouraging innovation. Generally, an electric skateboard can be purchased for the low cost of €200, however costs can vary to as high as €2000: *"Nowadays, you can find a solid model for well under $500"* [17].

Electric skateboards are a neat solution for a rideable. The user stands in a sideways stance with feet spread and positioned roughly perpendicular to the direction of travel. This wide gait allows the user to absorb bumps in the direction of movement.

However, electric skateboards do have some disadvantages. With their powerful BLDC motors, there can be strong acceleration which can be destabilising for new users. Riders who are inexperienced with skateboards may take some time to adjust to the balance and movement required. Generally, the wheels are quite small. Even the largest longboard wheels (110mm) struggle on rough or cobblestoned streets, creating an uncomfortable or impossible ride. Some boards come with all-terrain wheels. Although these might handle rough terrain better, level changes, such as curbs, are still impossible to traverse. Electric skateboards also have a large turning circle due to the limited mobility of skateboard trucks.

### B. *Scooters*

Electric scooters are an alternative rideable for commuters. With convenient handlebars at the front, they are significantly more user-friendly for the average commuter. The user stands facing forwards with one foot behind the other. This is not as sturdy as a skateboarding stance, but the handlebars add stability and support on uneven surfaces. However, as seen with the introduction of scooter rental schemes in the US, users do still struggle: *"Electric motors can accelerate surprisingly quickly, and the momentum a rider generates takes effort to slow down. Keeping a leg ready to brace for a sudden stop requires some practice"* [11].

Similar to electric skateboards, scooters have small, thin wheels and, as reported in [11]: *"the tiny wheels can get* *trapped by uneven sidewalks and grates, causing falls."* As with electric skateboards, the electric scooter has a large turning circle. The handle bars at the front also make it awkward to bring on public transport. Most scooters can fold to become smaller, although they do remain somewhat cumbersome.

Though these are one of the simplest to use and most common rideables, it is evident that there are still disadvantages that have not been addressed. Along with legislature problems [12], this is a clear limiting factor in their progress in popularity.

### C. Self-Balancing

Self-balancing rideables, such as unicycles and diwheels, rely on gyroscopic sensors and/or foot sensors to find the direction that the user is leaning. To counteract the lean, and balance the user, the rideable accelerates in that direction. Most self-balancing rideables, including the ones discussed below, use the same stance, where user faces forward with feet apart. This gives the user a strong stance for lateral movement, which is useful for turning, but a sudden bump or stop in the direction of movement could throw the user forward. It is also possible for the user to lean too far for the rideable to compensate, which will cause an accident.

The criticality of the self-balancing control system leaves the user very reliant on the electronics of the rideable, which, at high speeds, can be very daunting. As highlighted in [2]: *"electrical failures can cause a sudden and dangerous loss of pitch attitude."* As a result, all self-balancing rideables have a steep learning curve where finding balance and mounting/dismounting can cause problems for users. This has led to a number of injuries. An epidemiological study on the injury profile of diwheels, [20], noted *"safety equipment, such as wrist guards and helmets, should be worn in an attempt to reduce the number of injuries."*

*Unicycle*: Unicycles have a single, large wheel. The user stands on foldable foot platforms either side of the wheel and, as with all self-balancing rideables, controls the direction of movement by shifting their body weight. Due to instability in all directions, unicycles are very difficult to mount/dismount and usually require some support for the user such as a wall or pole. Balance cannot be easily kept while operating at low speeds. However, the large wheel of the unicycle is the biggest of all rideables at 14 to 18 inches in diameter. This makes moving over cracks and cobbles and traversing level changes much easier than any existing device. As the size of the device is not much larger than the wheel, unicycles are largely portable

*Diwheels*: Similar to a Segway but without the support column, diwheels (sometimes referred to as hoverboards) have smaller wheels and a slimmer base, making them lighter and easier to carry. However, the smaller wheels and lower ground clearance make traversing rough terrain difficult and level changes impossible to manoeuvre. Due to these disadvantages, diwheels are not yet seen as appropriate rideables for commuting. As explained by the inventor, Shane Chen [21]: *"to me it is just a toy. [...] It's fun. But you cannot use it for transportation. It's not practical."*

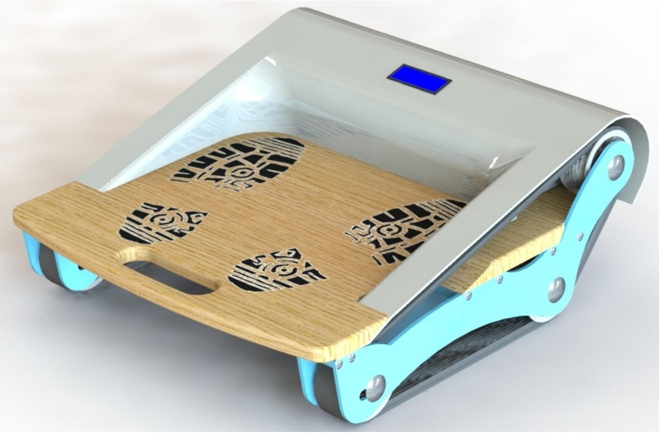

Fig. 1: A rendering of the TracPerT

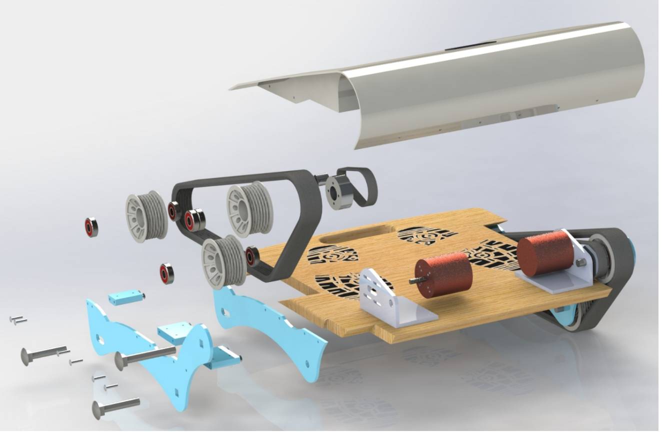

Fig. 2: An exploded view of the components of the TracPerT

## III. TRACKED PERSONAL TRANSPORTER

In identifying the deficits of existing rideables, solutions can be drawn upon in the creation of new rideables, specifically the TracPerT. From the above analysis, summarised in Table I, it is clear that a successful rideable should be easy to use, whilst being portable, versatile and secure in all terrains. The present authors believe that a design which embraces tracks rather than wheels can achieve these characteristics.

### A. TracPerT Design

The TracPerT consists of a large stable base with rugged tracks on either side. This gives a strong steady platform for the user, making it easy to use for any experience level. The tracks are raised at the front allowing it to traverse curbs and other levels changes and ignore cracks and small bumps. The tracks increase stability and allow mobility across all terrain types. The large area of surface contact make it ideal for traversing difficult terrain or loose ground. The TraPerT is designed to be small and light (<10kg) making it portable and ideal for intermodal commuting. It is a fully electric

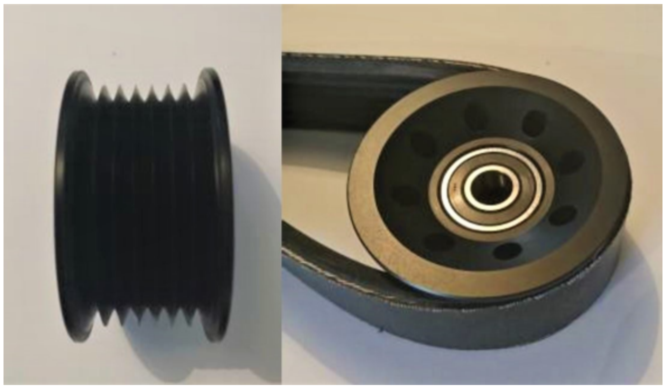

Fig. 3: The custom fabricated pulley wheels for supporting the poly-v belt

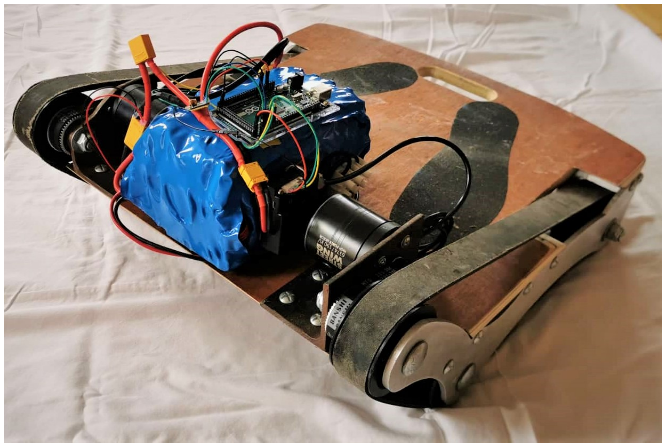

Fig. 4: A photo of the current construction of the TracPerT

device controlled by a handheld, wireless controller. Intelligent differential commands to the motors on either side will provide the steering capability.

The unique selling proposition of the TraPerT is that it is a portable, powerful, all-terrain vehicle perfect for the urban commuter or the off-road adventurer. It does not require smooth, paved cycle tracks or footpaths and is, therefore, ideal for travel in any town or city around the world.

### *B. Prototype Build-out*

*1) Mechanics of Device:* The TracPerT was initially designed in Solidworks with consideration given to how each component may be fabricated. A rendering of the concept for the device is shown in fig 1, with an exploded view showing the main components in fig 2.

The wheel mounts were machined from 12mm and 6mm aluminium sheets, held together by M6 bolts. A slot for the rear wheel axle allows the tracks to be tensioned. The track used is an L-section poly-V belt with the wheels fabricated to fit, as shown in fig 3. The wheels are fabricated from black Delrin and are fitted with two deep-groove ball bearings, as shown in fig 3. The two fore wheels are raised to lift the tracks at the front of the device. These fore wheels are driven by the motors via short toothed belts which provides some gearing flexibility, too.

The board's deck is machined from 18mm marine plywood. The motor mount is fabricated using a 75mm × 75mm × 6mm mild steel equal angle bracket. Mounting slots for the motor allow the drive belt to be tensioned. The pulley wheel mounting brackets are machined from 4mm aluminium. In the final design, a protective cover will be introduced to protect the user from the electronics, motors and moving tracks. This cover can also house an information screen for valuable information such as current speed.

*2) Power Electronics:* The tracks are driven by two powerful, 190KV (rpm/V) Brushless DC (BLDC) motors, rated for powers up to approximately 2 kW. These motors are controlled using two Vedder Electronic Speed Controllers (VESC) [4]. The motors are coupled to the fore driven wheels by a 3:1 synchronous belt drive system. With this gearing, TracPerT has an estimated top speed of approximately 25km/hr. This speed was estimated using the equation below, which assumed that speeds under load would could achieve 70% of the motor's no load operating point:

$$Speed = (KV)(V_{max})(60)(\frac{2\pi r}{1000})(\frac{MotorGear}{WheelGear})(0.7) \quad (1)$$

These motors are powered by a high capacity 10S (36V) battery pack, capable of delivering up to 40A to each of the two parallel connected VESCs.

*3) Control System:* The VESCs are controlled with an Arduino Mega 2560 over UART communication. Information such as motor rpm, motor voltage and current, and VESC temperature can be received and printed on a display screen for the user to view. The Arduino receives control signals over I2C from a handheld, wireless Wii nunchuk. The nunchuk is simple and intuitive to use with the thumbstick controlling direction and speed of movement. These control signals from the nunchuk are intelligently interpreted by the Arduino which dispatches commands to the motors to effect smooth acceleration and deceleration, with differential commands on either side used to achieve steering.

*4) Materials and Costing:* Table II shows an approximate pricing total for the development of the TracPerT. From this price table it is evident that a large portion of the cost of this prototype was in manufacturing the wheels and purchasing the motors, VESC and battery pack.

While the poly-V belt is a fine track for prototype testing, it is probably not ideal as an effective final solution for commercial design due to poor surface grip and a slight loss in power due to slippage on the drive wheel. Given more time on later prototype iterations, a more affordable and effective tracked system could be designed and implemented. A custom double-sided tracked belt would be more appropriate, the viability of which will be explored in later prototypes.

Similarly, further cost reductions can come in the manufacture of parts and once commercialisation begins, mass production of these parts will come at a reduced cost.

TABLE II: Indicative costings for TracPerT components

| Part | Quantity | Cost | Total |
|---|---|---|---|
| Board | 1 | €10 | €10 |
| Wheel Mount | 2 | €50 | €100 |
| Wheels (4 Idler, 2 Drive) | 6 | €66.67 | €400 |
| 1074mm Poly-V Belt | 2 | €25 | €50 |
| Deep Groove Ball Bearings | 12 | €5 | €60 |
| Motor Mount | 2 | €7.50 | €15 |
| Motors (BLDC) | 2 | €120 | €240 |
| Belt and Pulley Kit | 2 | €25 | €50 |
| VESC | 2 | €145 | €290 |
| 10S (36V) Battery Pack | 1 | €250 | €250 |
| Arduino Mega | 1 | €30 | €30 |
| Wireless Wii Nunchuck | 1 | €50 | €50 |
| Arduino OLED Display | 1 | €3 | €3 |
| | | **Total:** | €1548 |

The final construction of the TracPerT will weigh more than 10kg and is larger than the design intended, though this is not a concern for the initial prototype. Once design, power and control aspects have been established, further prototyping can look at reducing the size and weight of the TracPerT. Weight reductions can come in lighter manufacturing materials and size can be reduced with design improvements.

### *C. Testing and Validation*

*1) Outdoor Terrain Testing:* The current prototype device, shown in fig 4, has been subject to successful dynamic testing. With large weights placed on the base of the TracPerT it could effectively traverse rough terrain, such as gravel and grass. It easily climbed medium sized curbs and effectively ignored small variations in road and footpath terrain. The TracPerT has been test-driven by a user of average weight, and the motors and belt drive system appear suitably powerful for this use. A lack of traction in damp terrain or areas with minimal friction was evident. However, this was clearly due to the smooth outer edge of the poly-V belt used in the tracked system. A rugged, toothed exterior belt would negate this problem. Similarly, the BLDC motors were sufficiently powerful in all situations tested. However, there was occasionally some slip between the drive wheel and poly-V belt. Similar to above, this problem would be solved with a toothed belt on the interior and a superior belt tensioning mechanism.

*2) Future Work:* The control system of the TracPerT will continue to be improved and tested. Further improvements to the control system could include implementing a ‘hand-brake’ to the TracPerT using one of the nunchuk buttons. This brake could be useful while stopped on a hill. The other nunchuk button could be used to implement a form of cruise-control. Holding the button should keep the TracPerT at the current speed and the thumbstick can be left in the idle position. Pushing the thumbstick forward should increase the speed of the TracPerT and pulling the thumbstick back should slow the TracPerT. Left and right thumbstick movements should turn in the appropriate direction for the duration that the thumbstick is held in that position. Releasing the cruise-control button will revert the TracPerT to its regular control algorithm.

Once the core design and control system is implemented further improvements can be explored. Head lights and rear lights can be added to make the device safe for night time use. However, with the TracPerT being low to the ground, it would remain necessary for the rider to wear a light or reflective clothing on their person.

A larger, improved information screen could also be added to the TracPerT showing current speed, remaining battery range and battery status when charging. Improvements to the controller could also implement an information screen. This would be more convenient for the rider as it would provide ease of viewing. Future prototyping will focus on creating an optimal rideable design for commercialisation. This will include reducing weight and size of the device and improving its visual appeal. Optimising the convenience and power of the device will be the main focus whilst reducing the production cost.

## IV. CONCLUSION

This paper has presented a novel concept for a new type of rideable, the TracPerT, which uses tank style tracks to offer smooth mobility across all types of terrains. The advantages and disadvantages of existing rideables were explored and the novelty of the present proposal was situated in this context. The design and manufacture of the first powered prototype, the TracPerT, has been discussed and an indicative development cost outlined. This device has succeeded in its initial tests, and further work will continue to refine its control algorithms and to test it in more challenging conditions.

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