Hoverboard: Under The Hood

Reverse-engineering a fun product

By **Dr. Thomas Scherer** (Germany)

As Christmas approaches so does the obligation of delighting your children, grandkids or yourself with a present that will give great joy. If a Segway is beyond your budgets and the garage is already full of bicycles, a hoverboard must be worth a shot. Or is it? These devices are now widely available at affordable prices, on eBay for instance. So we dismantled one and checked it out to discover precisely what lies 'under the hood'.

A self-balancing Segway scooter is a marvelous fun vehicle. Maybe you have already 'ridden' on one while on vacation, or taken part in a Segway tour, and experienced first-hand how much pleasure this form of motion provides in the open air. But a Segway is not just heavy and bulky but at around €9,000 / £8,120 / $10,540 it's plenty pricey too. So expensive in fact that back in 2009 the Elektor Wheelie [1] provided an affordable construction kit for a fun chariot of this type and enjoyed great popularity.

Figure 1. An elephant on a hoverboard. But don't try this at home or at the zoo, as it's a slight overstatement unless you buy a proper jumbo version.

Figure 2. The contents of the carton are clear to see.

Time moves on… and further developments and variants arose. Segway was bought up by the Chinese 'cloner' Ninebot [2], which had previously offered cheaper (and nastier) near-replicas for under €2,700 (£2,440 / $3,160). As a subsidiary of the electronics giant Xiaomi, Ninebot had sufficient capital for this 'absorbing' version of technology transfer. Since then Ninebot has brought to market, alongside its classic 'Elite' and various one-wheelers, some additional mini models of a Segway replica for below €1,000 — in particular the 'Mini-Pro' design for an unbelievable €520.

How come? And doesn't safety suffer as a result of price reduction? There is talk on the Internet of some "unpredictable results" with Ninebot products and videos are circulating on YouTube of heavy falls involving these models. To be fair, they also occurred with the original Segway, although these were down to driver error or simple over-enthusiasm. And if Ninebots are not unproblematic, then how do things look for hoverboards, which have been around for about two years now and are even cheaper?

Basics

Under the titles 'Self-balancing scooter' (English), 'e-Board' (German) and 'Gyroskate' (French), Wikipedia contains relevant articles on this subject that also cover Segways. Some imprecision may arise from this broad classification. Specifically the hoverboard resembles a kind of mini Segway without a steering column; it is steered instead by displacing one foot against the other on the tread surfaces.

A hoverboard is therefore not a single, rigid footboard fitted with two wheels; as an alternative the tread is divided in the center with a joint between the two halves. By tilting sensor pads on these the rider can hopefully control the speed and direction of travel. The vehicle tries to maintain the tread plates horizontal. If the user leans slightly forward, the engines accelerate forwards, thus restoring the balance. When the user leans slightly backwards, the device logically also goes backwards. So far, so simple.

Purchasing pointers

In order to form a personal impression of how safe these hoverboards are, the Elektor editorial team decided to buy one of these personal travel devices. According to Google, the widest

selection of hoverboards and best prices are to be found on eBay. But first we did some deeper digging on the Net. Here you can encounter some remarkable whoppers, as **Figure 1** effectively demonstrates.

In our searches and comparisons it became clear not only that all models stem from China but also that there is fundamentally only one design. It comes in several price ranges, numerous colors and with a profusion of warranted features for which you need a wild imagination. In practically every country eBay has several thousand examples on offer. In terms of performance there appears to be little to differentiate one from another, as they all have two motors with apparently 350 W of power each. For that reason they all employ a lithium battery pack with 36 V and 4.4 Ah, in other words around 160 Wh of standing energy available, which should be adequate for up to 20 km. In most cases the battery pack is supposed to originate from Samsung. According to sellers, their vehicles move at between 12 and 16 km/h (8–10 mph) and can transport people weighing up to 120 kg (260 lb).

Aside from their gimmicks and colors, hoverboards are differentiated above all in the diameter of their wheels. These can be had with solid rubber tires in diameters of 6.5" and 8" (from €140 / £130 / $160 and €170 / £150 / $200 respectively). Deluxe models with 10" pneumatic tires start at €230 / £ 210 / $ 270 or with 8.5" air tires from around €250 / £225 / $290. You can buy carrying cases, remote controls and even integrated Bluetooth speakers that let you pollute the environment with music if you hook them up to your smartphone. Once this was clear, the author decided for one of the 10" variants without all the Bluetooth kerfuffle in a decent shade of black [3]. One click and two days later the parcel had arrived.

Unboxing and preparation

What you get in the carton can be seen clearly in **Figure 2**: the shiny brand-new Hoverboard (still adorned with excess strings of hot glue not removed after production) and to the left an AC power cable and a charger device (on top of the instruction booklet).

As for the power cable, this was crushed so badly in three places that there was a significant risk of short circuits (not to mention a 'stimulating' electric shock). An e-mail to the distributor's German warehouse brought a small package two days later with a new cable — plus a new power supply that had not been asked for. Unnecessarily good service!

A note in the carton explained that the battery pack was 'empty' and therefore need to be charged before using. I did as told and in 1.5 hours it was full. So what about the other 3 Ah? At this point, I also realized that it is not just a rumor when people on the Net talk about hoverboards catching fire during charging. **Figure 3** shows that the charger must be used unobstructed and well ventilated, and should never be covered.

On the bottom (**Figure 4**) you can see three stickers. The CE label is impressive only if you are unaware that manufacturers or importers self-certify their products. The safety instructions are to the right. Hardly any additional information is imparted by the amusingly so-called 'Other Sticker' on the left. To the left of the center joint is the start button and on the right a rugged, male charging socket with three pins.

Last but not least we come to the 'instruction booklet' — rightly put in quotes. It is four sheets of A4 paper. Of these eight pages two, set in very large print, contain very little content. Instead

Figure 3. After a while the small charger device gets decidedly warm.

of blather about CE symbols and so on plus the assuredly sensible warning to use the hoverboard only when wearing protective clothing (helmet, gloves and knee protectors). But some more in-depth information for newcomers would have been better. You can, after all, do yourself real harm, particularly during your first trials, and damage your home furnishings! To correct this shortcoming, we have assembled some tips for beginners in the text inset **Getting On Board For Beginners**. If you still want to buy a hoverboard after reading this report, study the text closely!

Inner workings

For people like us having confidence in technology depends on knowing it intimately. So the plastic casing has to come off, in order to get a proper view of the inner workings. **Figures**

Figure 4. Hoverboard underside with stickers.

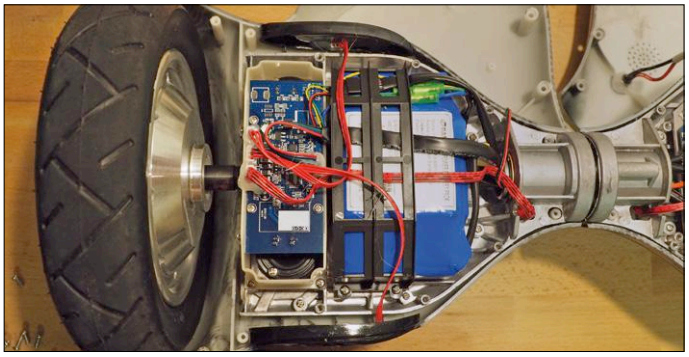

Figure 5. Left side uncovered, showing the foot switch and battery.

Getting On Board For Beginners

The best advice is

trust the hoverboard!

With hoverboards you play the key role in the balancing process. If you attempt to get onto the board from standing on the ground in the normal way while trying to keep your balance, then you have problems. The two dynamic control systems try to regulate in opposition, with different control speeds and amplitudes. Things can only go wrong! So let the hoverboard balance, then within a few seconds you get a feel how the apparatus behaves.
Your first attempts should be like this:

- Park the hoverboard on as smooth a surface as possible. Concrete is ideal. Lawns are a no-no.
- On the underside of the hoverboard look for a metal press-switch (see Figure 4). Push it once and a green symbol lights up on the top surface.
- Now place your left (or right) foot horizontally on one of the tread plates. Left and right are irrelevant on a hoverboard, as it drives equally well in both directions. When contact is made the green lamp lights up clearly.
- Now teeter (seesaw) with your foot slightly and feel how the board reacts. Do not rock it too much, otherwise it will take off at speed (and with luck then switch off).
- Now comes the point of no return, getting on board. Leave your first foot where it is and stand with the other foot on the opposite tread plate. Don't do this hesitatingly, nor too violently, but briskly.
- If you trust the hoverboard, now stand fully upright. It should feel completely stable, with very little wobbling. Keep still to begin with, developing a feel for the board's attempts to stabilize itself.
- Now you can start leaning forwards a little. You will – ooh, er! – move forwards. And discover intuitively how to brake and move backwards. Try this cautiously.
- Now you can check out how to teeter (seesaw) your feet in 'push-pull' mode: raise one foot gently and depress the other simultaneously. In this way you can make the lowered side move forwards and the raised side go backwards. You can turn around on the spot.
- Rotate the other way around. Practice turning in both directions; it may not be entirely intuitive but it's vitally important.
- Combine moving forwards with rotating, to turn curves. After five minutes or so you will more confident.

Children should be warned to be careful. As soon as they believe they have mastered the hoverboard, overconfidence sets in. Taking a curve too fast is a painful way of getting a physics lesson on centrifugal force.
It can help if you offer beginners a strong hand. The psychological support is more important than physical hand-holding.

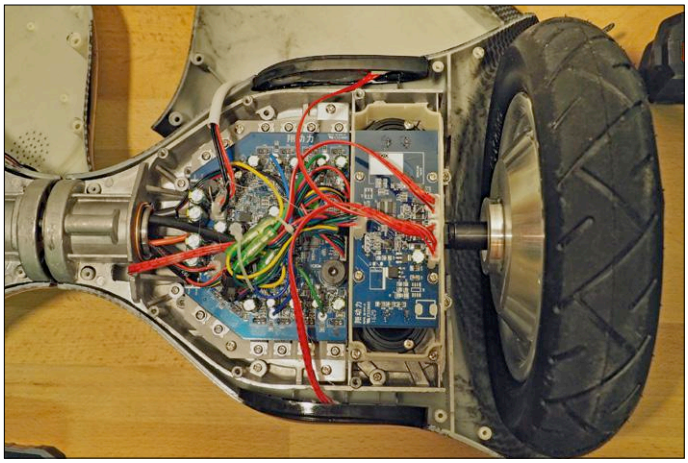

Figure 6. Right side revealed, with main board and foot switch.

5 and **6** show the left and right sides. First you can see the metal frame made of aluminum. On the left is the blue-jacketed battery pack, on the right the main board with twelve power MOSFETs (for 2 x 3 half-bridge or totem pole circuits) for controlling the two brushless DC motors. In each case, the boards for evaluating the step signals are shown on the outside of the wheels. The joint (**Figure 7**), an active component with angle sensors (the red cables left and right), is located in the center. **Figure 8** shows how a rubber plunger on the underside of one of the tread surfaces actuates the fork light barrier soldered on the blue circuit board. Obviously an optical principle is trusted more than mechanical switches here. In **Figure 9**, the circuit board is disassembled and inverted so that the two photocells can be seen clearly. To the right, you can see the two rubber plungers, and the flattened axle of the right motor is fixed between them.
Now for the batteries. Because I was curious whether they had really fitted Samsung cells, I undid the battery pack and stripped off its blue plastic wrapping. Inside we find some standard commercial lithium-ion cells of the 18650 variety – in all likelihood type $LiCoO_2$ – of which two were wired in parallel and ten in series, indicating the designation of 10s2p and a nominal voltage of 36 V. There was no sign of the word Samsung any-

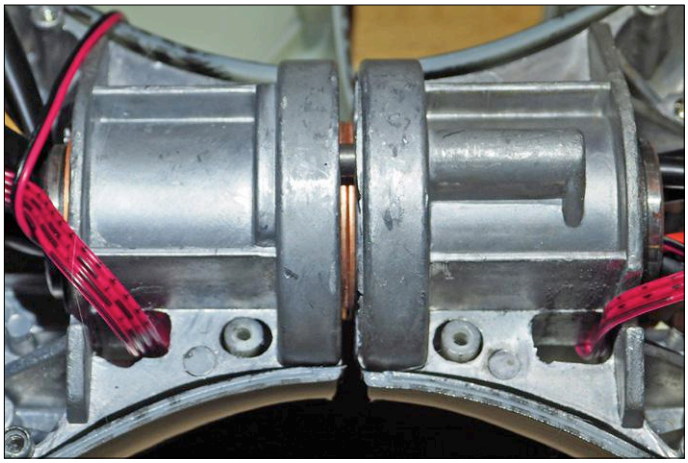

Figure 7. The swivel joint connecting the two halves.

where; instead it's a case of a no-name product. The capacity in Ah is nowhere to be seen either. However, as **Figure 10** indicates, the designation '7.2Wh' is clear to see, producing with a voltage of 3.6 V per cell a capacity of 2 Ah. In that case the battery pack's total capacity is definitely 4 Ah rather than the stated 4.4 Ah. A scam of 10%. But we can hardly quibble because all in all, considering the €230 demanded, we're getting a whole shedload of technology for our money.

Driving experience and the bottom line

First off, I possess not only a Segway 'driver's license' (dating back to the time when this was still required in some regions of Germany) but also sufficient experience driving the Segway and on board numerous home-brew creations from the Maker scene. Seldom have I felt more unsafe on a self-balancing electro-scooter than on the hoverboard. Even after an hour it didn't feel nearly as intuitive as after just five minutes with a Segway. Why should this be?

Balancing on pee-wee wheels

First up, owing to the method of turning curves by tilting the feet. This is far less intuitive than 'turning into the curve' on a scooter fitted with handlebars, where centrifugal force and gravity assist in maintaining your balance. If you make a fast turn with the hoverboard, you have to estimate how aggressively to turn into the curve, leaving the balancing entirely up to you. And there's the reaction time before you feel a response. Furthermore, it is difficult to coordinate the tilt angle of one foot against the other with the inclination of your body in the curve. The second aspect is the performance of the motors: 2 x 350 W, which we too would *like* to believe. But the Wheelie already had 2 x 500 W and other clones a solid 2 x 1 kW. An original Segway delivers a peak performance of 2 x 1.5 kW. Frankly a hoverboard is underpowered. My brow furrows at the 120 kg permissible load, because even with my 90 kg body weight the term 'acceleration' is fanciful. And when you have a shortage of power, even the most superb speed control is of little use.

On top of that, even at 10" the wheels are still on the small side, performing particularly badly on uneven surfaces. During my attempt to use the hoverboard on my back lawn, which is admittedly not quite up to English standards of evenness, I had to break off after 30 feet or so, with sweat beads on my brow. A hoverboard is no plaything then. It should be ridden only on flat ground without any loose gravel and using protective gear (never without a helmet!). And probably not by the older generation, because their offspring have better sensory and motor functions for dealing with this kind of device. Besides, they usually weigh less. Personally I would not let children under 10 years use them and above all never on the street (which is not allowed anyway). Out among traffic all of those CE labels provide no protection whatsoever.

By the way, the hoverboard survived teardown without ill effects...

(160508)

Web Links

[1] Elektor Wheelie: www.elektormagazine.com/magazine/elektor-200909/3360

[2] We need to make clear that although Segway filed a trade complaint alleging Ninebot and other Chinese companies had violated its patents, Ninebot asserted that it "independently owns its intellectual property."

[3] Black 10" hoverboards on eBay: https://goo.gl/8oDgy2

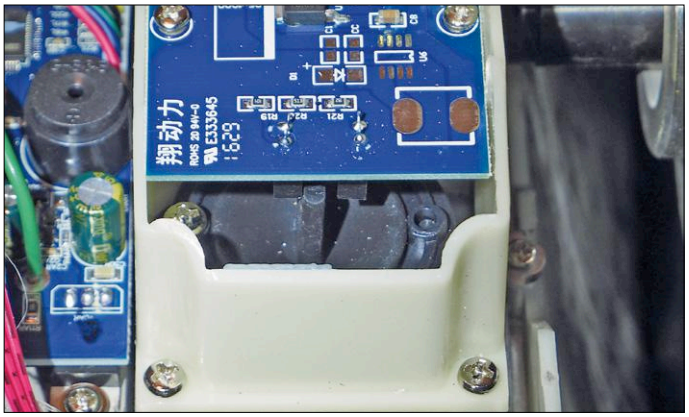

Figure 8. Foot switch with rubber plungers and light barrier seals.

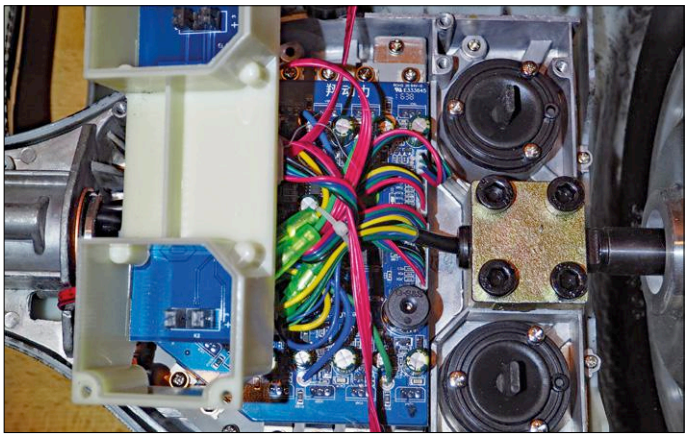

Figure 9. Foot switch opened up: two plungers and their light seals, also showing the attachment of the wheel axle.

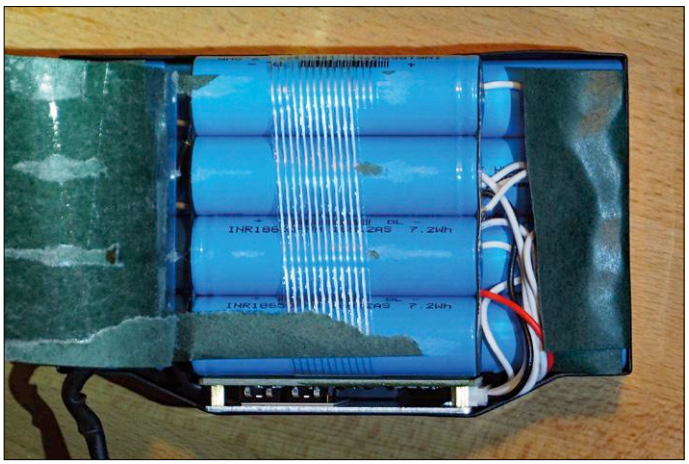

Figure 10. The battery pack stripped bare. No sign of any 'Samsung' markings.