Energy Consumption of a Hexspider Robot-o as Function of Footwear and Underground: Experimental Investigations

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Abstract: In this paper, the previously designed and implemented spiderino robot-o, or a robot used to act in a swarm for educational purposes, is investigated regarding his energy-consuming properties. An experimental setup consists of a platform inside which the spiderino robot-o can freely move with a fixed random movement program. Furthermore, the robot-o feet were equipped with footwear made of materials with different friction coefficients, non-equipped or plastics, equipped with cork, equipped with rubber, and the underground was chosen to be stone, wood, plastics, and with regard to floor inclination for all variants flat and for the stone variant also inclined by 10%. The results show a characteristic curve in energy consumption according to a slightly different behaviour concerning the material combinations of footwear and floor, which adapts energy consumption physically due to the specific footwear-underground combination.

1 INTRODUCTION

Cyber-Physical-Systems (CPS) or devices are usually controlled by microcontrollers, as the widely used Arduino platform, which is comprehensively described in (Borchers, 2013).

In Internet of Things (IoT) systems on the other hand, or systems that are widely connected, and that are usually a CPS, the energy consumption is of great importance, because of battery need, long term unassisted usage and independent operation. A theoretical approach how to reduce energy efforts in IoT systems is done in (Demigha and Khalfi, 2019) by means of a linear temporal logic approach, which allows for exhaustive investigation of possibilities by creating Kripke automata, Petri nets, finite state automata etc. In this paper, however, we investigate a specific applied and related to mechanical experimentations approach of the question of how to reduce the amount of used energy as a function of material surface contact pairing parameters.

In education the approach of using low cost swarm robots (Elmenreich et al., 2015; M. Jdeed, 2017) is used, which we call here spiderino robot-o, directing to an orgiton of i-th order, which is a cybernetic unit of a robot, that acts in a swarm as a ‘hyper-organism’ (cf. also (Heiden and Tonino-Heiden, 2022a; Heiden and Tonino-Heiden, 2022b)). A theoretical and numerical study has been done on the ‘spiderin-o’ to investigate a minimal communication experimental setup with sensors and actuators consisting of emitted and observed LEDs (Heiden et al., 2021a).

The spiderino robot-o is as well an educational tool as a prototype for industrial production. Once established, a lot of applications are available. Classes from all ages can be taught and further on an implementation in the school and university system in assisting with easy to medium tasks developed. Basics kits of spiderin-os or spiderino robot-os should be given for the teaching system.

Content. In this paper we give in Section 1 the goal of the paper. In Section 2 we explain the position of this paper. In Section 3 we describe the spiderino robot-o that we investigate. In Section 4 we look at the experimental setup, first in Section 4.1 giving

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general considerations, then in Section 4.2 the experimental results of energy consumption by comparison of different footwear. In Section 4.3 we are looking at the energy consumption measured by comparison of different floors, and in 4.4 at possible logistics applications to this now educational approach, in future also applying to industrial and societal technological applications. In Section 5 we draw conclusions, and in Section 6 we give a summary and an outlook to the energy consumption of the spiderino robot-o and related research and application approaches.

Goal. The goal of this paper is to investigate the energy consumption of a spiderino educational robot, here referred to as spiderino robot-o, as a function of different varying environmental conditions with regard to friction, and plane inclination.

2 POSITION

The position of this paper is that we can influence the energy consumption of a spiderino robot-o to reduce energy usage in general by means of mechanical friction surface pairs. We further assume that the hypothesis is true, that we can discriminate by suitable measurement the effects that have significant impact on energy consumption and that we can optimise the energy consumption of the spiderino robot-o with regard to the surface conditions by a suitable equipment, which is in our case footwear, by this influencing a pairing of two contacting surface materials in the spiderino robot-o environment relative motion problem.

3 BACKGROUND: ROBOT-O

When we regard a robot-o we regard different levels of organisation. This can be seen, as different identical spiderin-os which then lead to a group of interacting systems which would be the first consideration of a spiderino robot-o$_i$ i=0 relating to a single and i=1 to, e.g. a group. In our investigation we regard another differentiation, of a robot-o, and this is one spiderino, with regard to different alternating conditions, of his footwear, or exchangeable outfit, and a fixed nearby environment, the different floors. The other one is the far distant environment or the outside of the experimental situation window. This 'window' can be regarded as the cage in which the spiderin-o, is allowed to move (see Figure 2), which is then the observed room, or the system-border, in this case of the experimental setup. So what we get is an orgiton of a combinatorial setting of near and distant environment, which could be indicated by two indices in our investigation. The spiderin-o^a_b relates then to a as the type of footwear, and b to the type of ground. In fact the intermission of a 'wear', changes the relation of a system to its environment. On the one side it is a shield, increasing some kind of 'distance', as well as physical conditions, like the weight increase. So this interaction relationship changes, with regard to friction, as we had intended to investigate in the experimental setup. The friction $\mu_{a,b}$, is the physical bidirectional interaction variable. Here we investigate this relation to the total Energy consumption E for movement for the spiderino, which hence can also be regarded as an optimisation problem of movement of a body, a robot-o as a function of $\mu_{a,b}$. The problem formulation is hence according to equation (1),

$$E(\mu_{a,b}) \stackrel{!}{=} opt \tag{1}$$

where the sign '!' translates for 'it should be' and the phrase 'opt' for 'optimum value', which is a minimum in this case, as the minimum conditions for energy consumption of the robot-o shall be met, or maximum with regard to time, or distance covered.

4 EXPERIMENTAL SETUP

In this Section we give first some considerations, then the results with regard to energy consumption of the measurements and later on how the spiderino can be related to industrial applications.

4.1 General Considerations

Concerning the experimental setup as indicated earlier, different combinations of material of the footwear a and the grounding b were done. The footwear was a=standard plastic, cork, rubber. The ground was b=wood, stone, carpet, and with regard to inclination 10%. The inclination was tried to be steeper but it turned out that a steeper gradient had led to instable movement of the robot-o so that it turned over in that case. So we restricted the experimental setup to an inclination that was save enough for constant safe continuous movement in all directions. In any case the movement of the spiderino can be regarded randomly, due to the experimental setup.

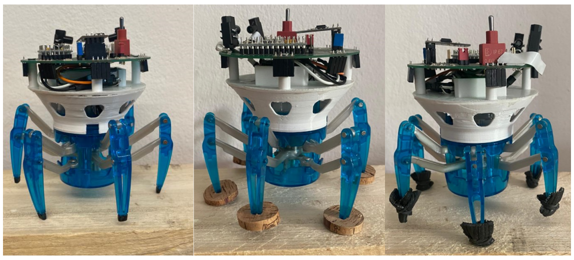

Figure 1: Robot-o with standard, cork, and rubber footwear from left to right according to (Koren, 2021) .

Figure 2: Robot-o platform and measurement according to (Koren, 2021) .

4.2 Comparison of Different Footwear and Floors

In Figures 3-9 the different footwear of the robot-o is shown for all the different floors, as well as the consideration of 10% inclination for stone floor. As a result we can see a wide spread in results for the standard footwear and a low for rubber on different grounds. Rubber seems to be equilibrating the results as was the case with the effect of inclination and the domination of gravitation over other effects. Hence it seems that in the specific material pair combinations rubber has a dominating effect as material. In general the wooden floor is best, except with rubber footwear, here there has occurred an inversion, the stone floor is relatively best according to Figure 9.

4.3 Energy Consumption

When we look at the energy consumption of the robot-o we would have to know the velocity of movement, and when we assume it as constant, then we have a mean constant increase in height and the height would be like in equation (2) proportional to t.

$$h \sim t \rightarrow E \sim t \tag{2}$$

Now when we assume E to be the potential energy

$$E = E_{pot} + E_x = m \cdot g \cdot (h + x) \tag{3}$$

then it follows

$$\frac{E}{m \cdot g} \sim t \sim (h + x) \tag{4}$$

Now having two robot-os with different mass m_1, m_2, due to their footwear as in the experiments, and also different Energies E_1, E_2, we get the relation at the same time:

$$\frac{E_1}{E_2} \sim \frac{m_1}{m_2} \tag{5}$$

When we take 1 for standard and 2 for rubber or cork: m_1=119 g and m_2 = 120 g then

$$E_2 \sim \frac{m_2}{m_1} \cdot E_1 \tag{6}$$

$$E_2 = \gamma \cdot \frac{m_2}{m_1} \cdot E_1 = \gamma^* \cdot E_1 \tag{7}$$

From the experiments we get γ^*=1.0005 in Figure 6. The measurements of the masses are at least in the same measurement range of the measurement instrument (+-1g), that there would be necessary a more accurate measurement, and hence the factor m_2/m_1 can not be determined from the data correctly otherwise. The measured data indicate that there is a homogenisation of the inclination, which means that the effect of the used materials is smaller compared to energy consumption. Anyhow, it seems to get improved by means of elastic feet, relatively. The homogenisation, might also have occurred due to the slight mass increase of the rubber and cork footwear variant compared to the no-extra footwear variant, but this should be re-evaluated after having done more accurate measurements, due to the above given argumentation.

4.4 Logistics Applications

A model of the spiderino robot-o, presented in this paper, can be seen as a basic scalable system for a wide variety of applications (cf. also (Heiden et al., 2020)). One of the most important application fields of such a robot-o is, e.g. logistics. In view of actual trends towards autonomous vehicle systems, the upscaled spiderino robot-o can take over transport assistant tasks for industrial and private purposes. Taking into account its advantages while driving on difference surfaces and with different types of footwear as well as its spider-like construction, it can potentially be used, e.g. for private mobility assistance. In (Bösch et al., 2018) a cost-performance analysis

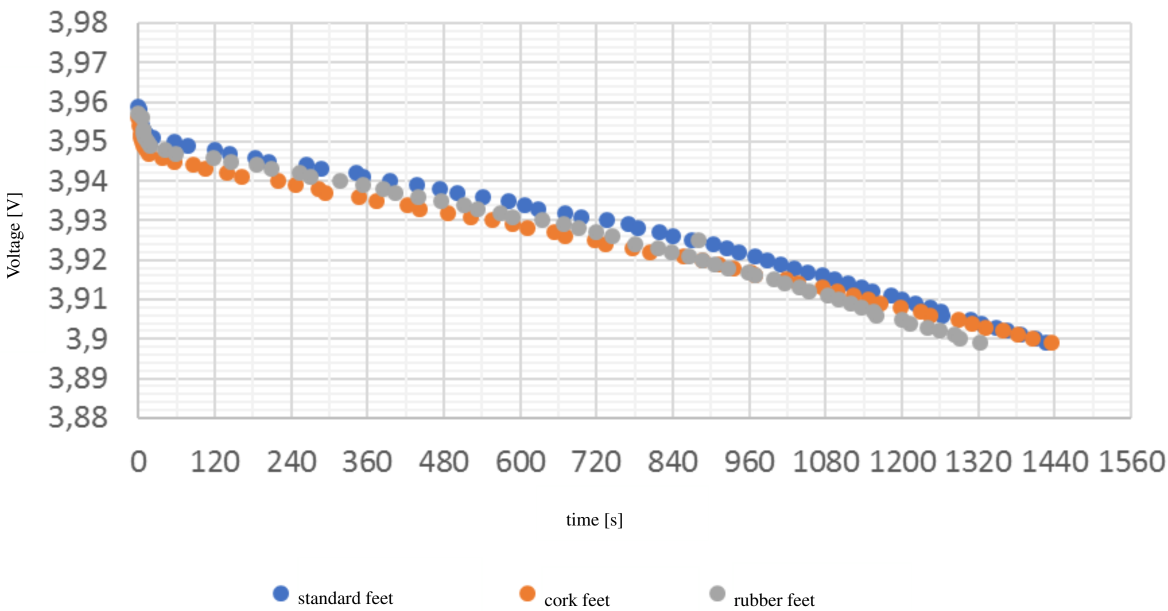

Figure 3: Robot-o on wooden floor with different footwear according to (Koren, 2021).

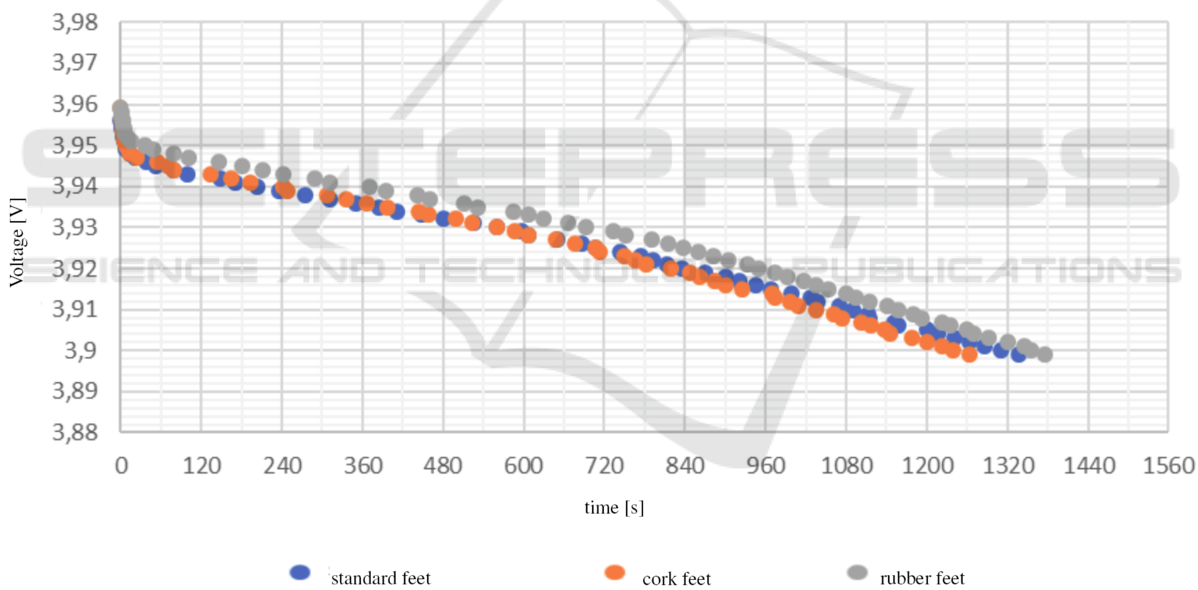

Figure 4: Robot-o on carpet floor with different footwear according to (Koren, 2021).

of different autonomous mobility services was carried out, which emphasises beneficial usage of private mobility robots in the future. In addition to this, good energy performance of the described robot, while moving on the stone surfaces, allows to suggest, that it can also be used in the industrial context, e.g. for transport operations in mining industry (Corke et al., 1998) for discussion of robotics application in mining industry). Overcoming of slopes can also be a topic of interest for future research. In case of a possible decrease of energy consumption, while overcoming different inclinations, the construction of a scaled robot-o, especially with spider-like feet, can be an advantage, e.g. for stair climbing solutions (cf. also (Heiden et al., 2021b)).

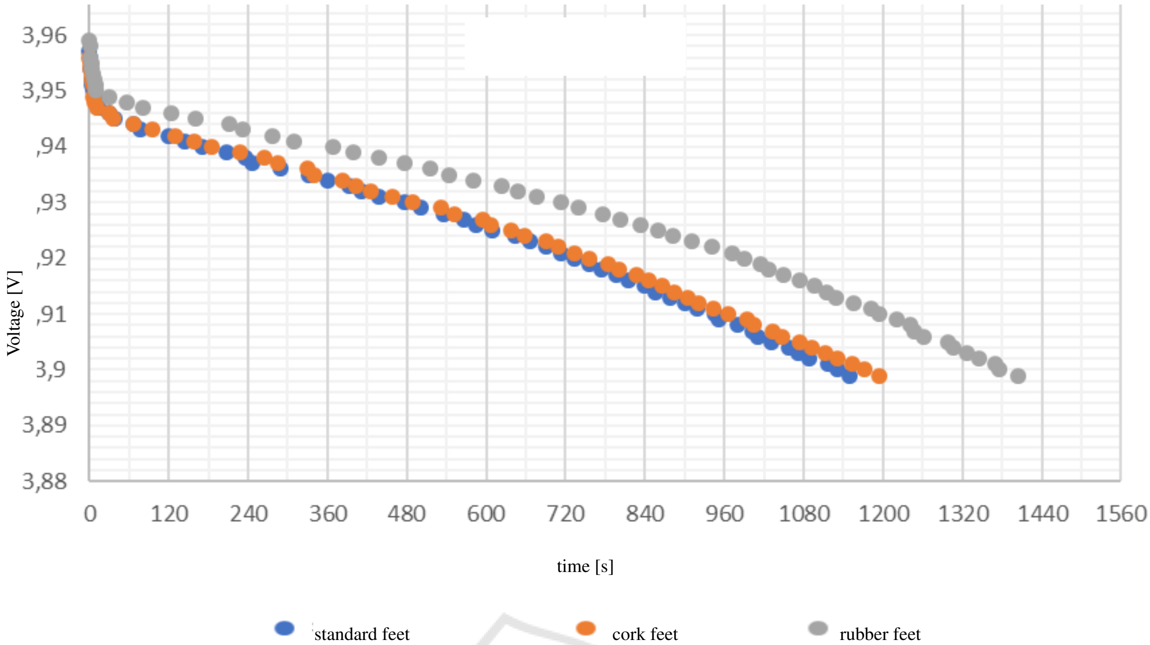

Figure 5: Robot-o on stone floor with different footwear according to (Koren, 2021).

5 CONCLUSIONS AND DISCUSSION

In this paper the energy consumption of a spiderino robot-o was investigated in dependence of different footwear materials and different floor types. For this purpose, the discharge rate of the 3.7-volt Li-Po battery, which is the energy source of the spiderino robot-o, was analysed and the voltage values depending on time have been measured (V(t)). It has to be mentioned that rubber feet showed slightly outperforming results on the carpet floor and significantly outgoes other feet materials on the stone floor. In addition to this, it has been shown, that the spiderino robot-o masters the 10% inclination in a relatively similar fashion with different footwear.

Due to the manual evaluation of experimental results, the differentiation between many value curves is not explicitly noticeable. For a future better differentiated measurement, devices with higher precision should be used, which can be also followed from the achieved measurement accuracy according to measurement equipment specifications (see Figure 10). Furthermore, the spiderino robot-o can potentially be scaled up for the purpose of industrial or private logistics applications as described in Section 4.4.

As from the reviewers was asked what the explanation is for the time period of two hours the answer is due to at least two reasons. First, this time is related to the battery time that is possible for one experimental run with this battery type. Second the measurements were made, although originally planned with another measurement device, with a manually to be operated device, and synchronised with a handy video observation time measurement, which was transcribed manually. The work was done 2021 in the course of the summer semester.

6 SUMMARY, AND OUTLOOK

In this Section we first give a summary and then an outlook.

Spiderino – Summary. The spiderino robot-o is an improved and modified toy robot, which has been equipped with an Arduino board to fulfil special missions. It has been tested on different ground levels and how it 'reacts' to an ascent. In the undertaken experiments the shoes have been alternated or changed as well as the different grounds. The measurements with an upgraded 3.7-volt Li-Po battery have been recorded and evaluated concerning its battery discharge. After the approximately two hours of measurements, the battery status has been nearly the same level of discharge at all ground levels, which is explainable

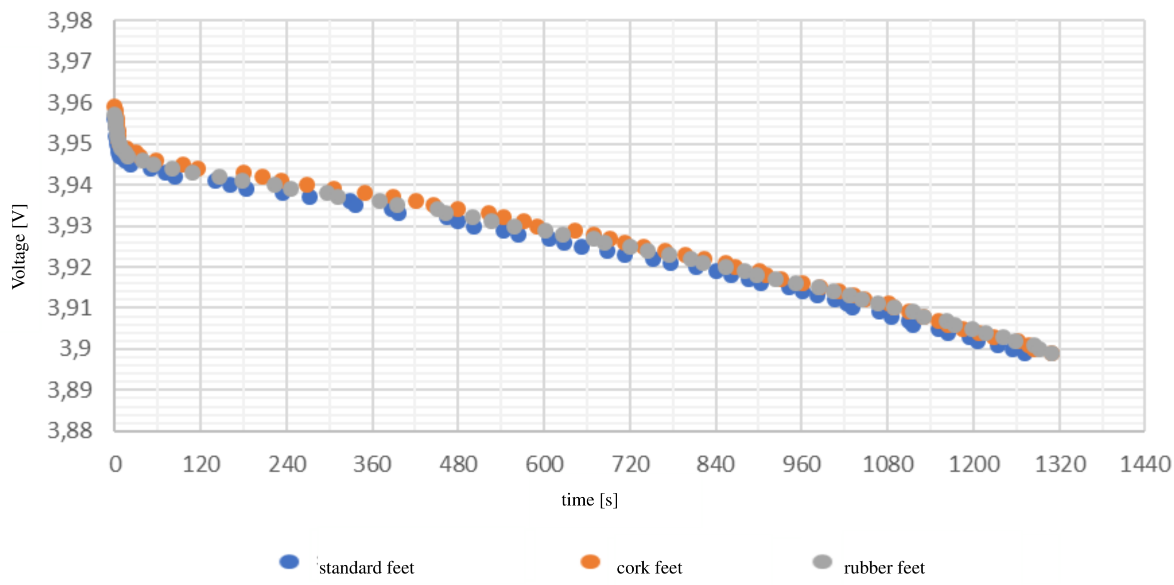

Figure 6: Robot-o on stone floor with 10% inclination with different footwear according to (Koren, 2021).

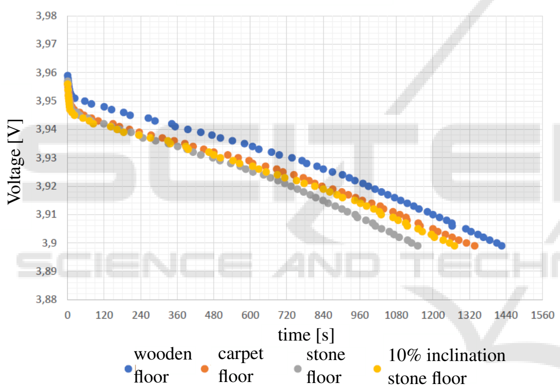

Figure 7: Robot-o on different floors with standard footwear according to (Koren, 2021).

by a discharging curve leading to the horizontal axis.

Outlook. More measurements and experience data should be collected and displayed, especially about the direct influence of friction on the discharge amount and how the various friction pair correspond to each other. Further the comparison between the friction pairs should be investigated, and whether they make a difference, as well as the correlation from the friction coefficient and the specific ground level and how the discharging level coheres with friction.

Research question of interests would also be how the movement pattern for different inclinations looks like in comparison to the planar levels, especially with new leg and body constructions.

As we have looked in our investigation at indoor materials, also outdoor materials should be addressed

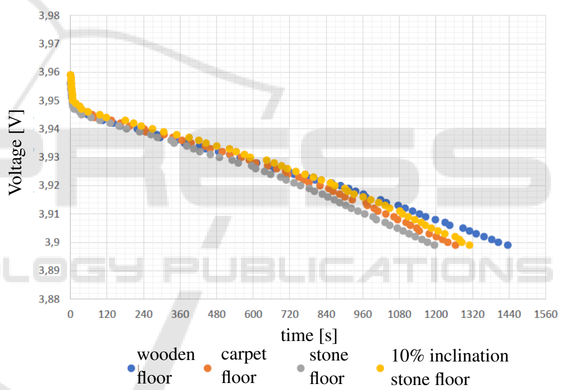

Figure 8: Robot-o on different floors with cork footwear according to (Koren, 2021).

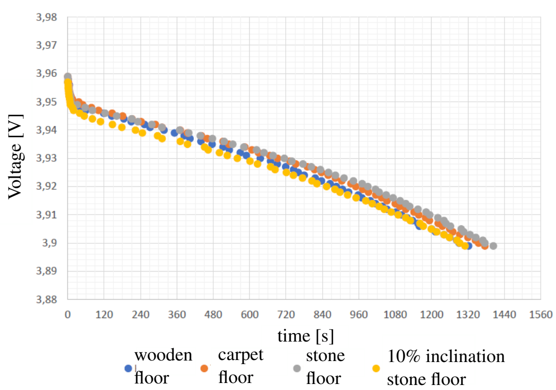

Figure 9: Robot-o on different floors with rubber footwear according to (Koren, 2021).

in future research. According to the geometry of the

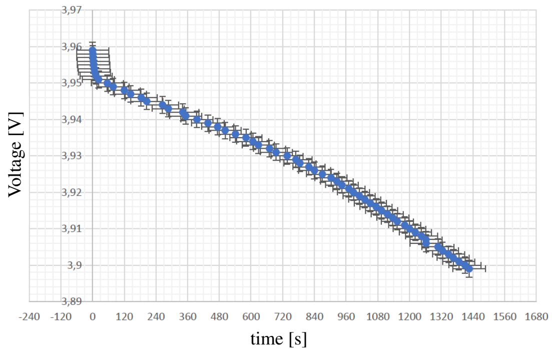

Figure 10: Robot-o on wooden floor with standard feet according to (Koren, 2021) and expected measurement accuracy.

spiderino robot-o, here the specific difficulty of differently inclined movement could also be investigated and how this could be overcome and or compensated for successful movement, with possibly then very different types of spiderino robot-os or environmentally suitably adapted robot-os in general.

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