

Electronic Differential Implementation in a Delta-Type Human Powered Tricycle

Theodoros Kosmanis, Georgios Koretsis, and Athanasios Manolas
Alexander TEI of Thessaloniki

ABSTRACT

The implementation of an electronic differential system in a delta-type, electrically assisted, three wheel Human Powered Vehicle is the subject of this paper. The electronic differential algorithm is based on the turning angle of the vehicle and its geometrical characteristics. The theoretical analysis is applied in a realistic human powered tricycle constructed in the premises of the Alexander Technological Educational Institute of Thessaloniki. The system's efficiency is validated through test measurements performed on the rear wheels during vehicle's operation in appropriately selected routes. The measurements are performed for both typical cornering and oversteering.

CITATION: Kosmanis, T., Koretsis, G., and Manolas, A., "Electronic Differential Implementation in a Delta-Type Human Powered Tricycle," *SAE Int. J. Commer. Veh.* 7(2):2014, doi:10.4271/2014-01-9028.

I. INTRODUCTION

Human powered vehicle (HPV) is the name given to a tricycle or a bicycle having the characteristic of a recumbent position for its driver and, in most cases, a fairing that encloses the vehicle [1], [2]. The HPV is very popular in places of relatively flat ground morphology for urban transportations instead of typical bicycles. It is also used for special racing events, like the World Human Powered Speed Challenge organised in USA by the International HPV Association (IHPVA) or competitions organised annually by the World HPV Association (WHPVA) in Europe.

The original version of the HPV is only human powered. However, versions of electrically assisted HPVs, with their mechanical drivetrain being coupled with an electrical one [3], have gradually appeared. The addition of an electrical drivetrain extends the range of the HPV, independently of the driver's physical condition, making it more attractive for usage in places of abnormal ground morphology. The three wheel, electrically assisted HPV can be found in two versions depending on the wheel positions. The tad-pole HPV has two front and one rear wheel while the opposite stands for the delta HPV, which is the less popular case.

As in all electric vehicles having in-wheel traction motors, the three wheel, electrically assisted HPV can be a field of torque vectoring (TV) implementation. That is, the mechanical or

electronic variation of the amount of torque sent to each of the driving wheels in order to improve traction and maximize a car's cornering ability [4],[5],[6],[7],[8],[9],[10],[11],[12],[13],[14],[15],[16],[17],[18]. Most Original Equipment Manufacturers (OEMs) [4],[5],[6] have constructed and presented TV systems for various types of vehicles, like conventional AWD and purely electric ones. They can be divided into two large categories, (i) electronically controlled mechanical systems (mechanical differentials), producing torque during braking and driving procedures [4], [7], [8] and (ii) purely electronic systems that rely on the operation of more than one electric motors to each or some of the four wheels [9],[10],[11],[12]. Combination of the two cases could also be found in AWD hybrid vehicles where the front wheels are moved by an internal combustion engine and the rear wheels are moved by one or two electric motors.

Of significant importance are the methods used to control torque in TV, like for example torque proportional to the wheel vertical load and torque distribution that allows achieving the same longitudinal slip ratio on each wheel [9]. Other methodologies are based on PID or adaptive PID control [13], second order sliding mode theory [14], [15] and fuzzy logic [16].

In HPVs, however, there is no need for complex control algorithms that might require expensive and inappropriate for tricycles sensors and actuators. On the contrary, simplified TV or electronic differential procedure can be applied, that is, traction wheels' angular velocity can be appropriately adjusted

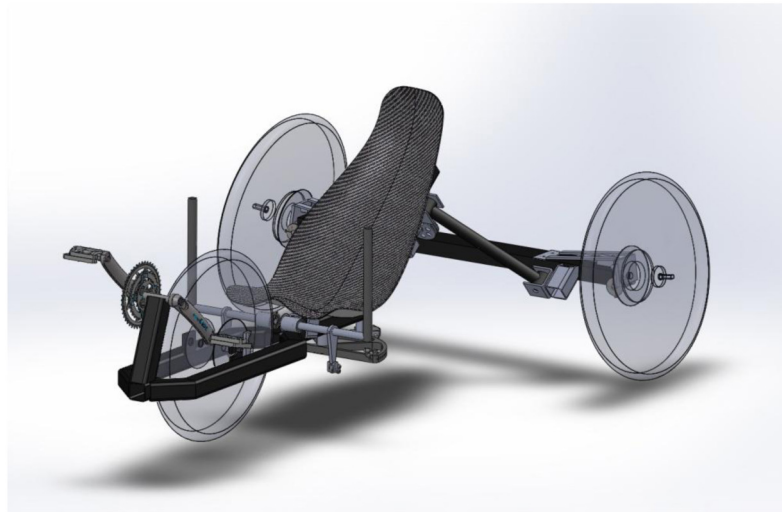


Figure 1. HPV 3-D drawing.



Figure 2. Constructed Delta-type HPV.

through control of the corresponding motors' operation as the outcome of an algorithm taking into account the geometry occurred during HPV cornering [20], [21] instead of complex algorithms and structures.

In this paper, the implementation of electronic differential in a three wheel, electrically assisted, delta HPV is presented. The constructed HPV is equipped with two rear in-wheel motors, the power converters of which are controlled by a single controller which decides on the motors' angular velocity. The algorithm selected takes into account the turning angle and the geometrical characteristics of the HPV in an effort to keep implementation as simple as possible and cost as low as possible. The electronic differential was validated through various test routes of the HPV, under typical cornering and oversteering conditions. The remaining of the paper is organised as follows: [Section II](#) presents the HPV constructed and its electrical drivetrain. In [section III](#), the

electronic differential implemented is theoretically described. Finally, [Section IV](#) presents the results from the measurements performed.

II. THE CONSTRUCTED HPV

The HPV used for the implementation of the electronic differential was constructed in the frame of a short-term educational program (EU Erasmus LLP Intensive Programme) about the HPV technology ([Figures 1, 2](#)). The characteristics of the HPV are given in [Table I](#) and [Figure 3](#).

The electrical drivetrain of the HPV together with its control network is depicted in [Figure 4](#). The power link consists of the battery pack, that directly powers the two motor drives. Two high discharge rate, LiFePO₄, 5 cell batteries of 18.5V voltage and 8Ah capacity each, are connected in series, providing 37V

DC voltage to the traction system. Each wheel is composed of a 1kW, in-wheel BLDC motor with its power converter, thus allowing minimization of the overall bulk of the electric drivetrain. In between the energy source and the motors a voltage and current measuring kit is adjusted in order to provide their values to the HPV controller.

The heart of the control link is an Arduino MEGA2560 microcontroller board based on the ATmega2560 microcontroller [22]. The inputs to the board come from the throttle lever of the HPV, manually controlled by the driver, an inclinometer appropriately mounted on the HPV chassis in order to measure the turning angle of the vehicle during cornering, and the power voltage/current measuring kit, providing the voltage imposed at the two in-wheel motor drives and the current drawn by them. Also, the Hall sensor signals from each of the rear wheels is sent as a feedback to the microcontroller. Sensor signals are received every 1 ms (sampling period), that is the data acquisition frequency is 1 kHz. During this sampling period, HPV velocity and turning angle are estimated from the corresponding analog inputs of the Arduino board. Also, electronic differential equations from Section III are calculated to provide the control signals to the motor drives. The differences between the desired and actual (Hall sensors) velocities are calculated too. All measured and calculated values are stored in a data logger mounted on the

Arduino board. The controller's outputs are connected to each of the motor drives, fully controlling their operation, and to a display providing useful information to the driver.

As far as the motor control concerns, the electric motors' actual control is performed by their drive, mounted with them inside each wheel. Arduino microcontroller is connected to each motor drive providing the signals with desired velocities. Each signal is the input of a PID controller that also receives signals from the Hall sensors of the corresponding BLDC motor. Therefore, response smoothening of the overall system is performed by each motor drive according to the PID programming.

It is noted that a Arduino microcontroller is also connected to a display that informs the driver on current conditions of the power system, that is the battery voltage and current intensity, the HPV and the motors' velocities and the actual turning angle.

TABLE I.

CHARACTERISTIC	VALUE
Rear wheel to wheel distance, d	1.1m
Rear to front wheel distance, L	1.09m
Wheel radius, r	0.258m
Total length, L_v	1.84m
Total width, W_v	1.24m

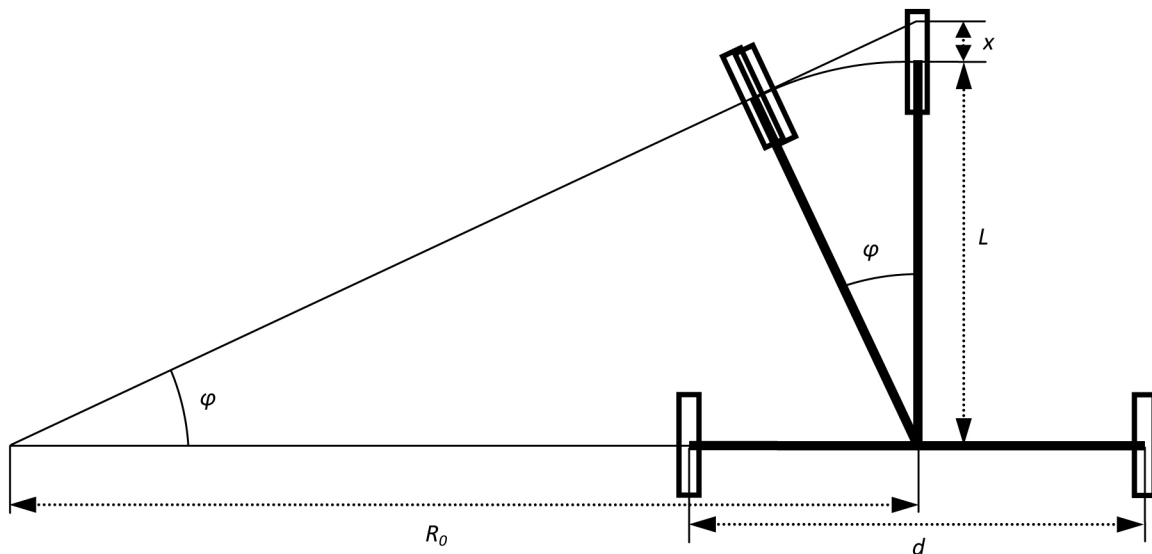


Figure 3. Delta HPV during left cornering.