Strategy control of drive mechatronic system for Virtusphere with two actuators

Lidia-Cristina Bazavan
Mechatronics and Robotics Department
Faculty of Control, Computers and Electronics, University of Craiova
Craiova, Romania
lidia.bazavan@edu.ucv.ro

Horatiu Roibu
Mechatronics and Robotics Department
Faculty of Control, Computers and Electronics, University of Craiova
Craiova, Romania
horatiu.roibu@edu.ucv.ro

Nicu George Bizdoaca
Mechatronics and Robotics Department
Faculty of Control, Computers and Electronics, University of Craiova
Craiova, Romania
nicu.bizdoaca@edu.ucv.ro

***Abstract*—The studies performed by the authors on Virtusphere (VS) platform led to identify solution to improve the feeling of immersion provided by a virtual environment. It was concluded in a previous paper that this feeling could be achieved by upgrading the VS with a mechatronic system. First experiments were performed using one brushless DC (BLDC) motor to determine if the actuation method and the control strategy suit application requirements. These were validated by comparing the results of the MATLAB / Simulink simulations with the practical results. To further enhance the system's effectiveness, the authors propose an additional actuator. This paper presents improvements to the drive mechatronic system for Virtusphere (DMSVS) and a strategy to synchronize the two motors with the user's movement. Using two in-wheel motors to reduce power transmission elements, a series of experiments were performed to implement the synchronization equations. At the end of this article will be presented the results of these experiments and conclusions about the control algorithm with simple wheels and with the new omnidirectional wheel design developed by the authors.**

Keywords— Virtusphere, BLDC, in-wheel motor, mechatronic system, synchronization equations.

I. INTRODUCTION

Virtual Reality (VR) is an environment generated by computers, and, for a user to be able to view it, he/she needs a special device named Head Mounted Device (HMD). This device is covering the full field of view for the user, which can result in injuries if the user is moving around. To allow the user to move freely into VR but also for enhancing the feeling of immersion were created omnidirectional platforms.

Virtusphere (VS) is an omnidirectional platform designed to be integrated with virtual environments. VS is similar with a hamster wheel in which the Virtual Reality (VR) user can move freely. The platform is purely mechanical and only has an optical sensor that provide information about sphere movement to VR application [1-3]. To improve the feeling of immersion into VR, the authors proposed a mechatronic system consisting in two in-wheels motors to train the sphere.

The drive mechatronic system for Virtusphere (DMSVS) was inspired by the trackball mouse, except that now the sphere is trained by wheels. DMSVS is using Brushless DC motors for the ease of control and are embedded in wheels to eliminate the need of power transmission elements. The two in-wheel motors are placed perpendicular on each other on X and Y axis and mounted on the metallic support of the sphere.

In Fig. 1 is presented the system's concept on a schematic manner consisting in sphere, metallic support and two wheels placed on the sphere and perpendicular on each other.

Figure 1 DMSVS concept

The system was developed by authors starting from idea of inverse mouse or trackball mouse. The mechanism of a ball mouse is: the ball trains 2 wheels with encoders to detect the movement in a plan. For DMSVS the mechanism is reversed: the wheels are training the ball into motion. With this system the feeling of immersion can be improved by providing feedback to the user inside sphere.

Tests on the system started with one wheel and were already published. It was determined the efficiency of the motor, the optimal control method and it was defined a control algorithm. After the tests for one wheel have been completed, the authors started working on the synchronization between two motors. The system, as well as the tests results and synchronization equations will be presented in details in the following chapters.

II. IN-WHEEL MOTOR TESTS

The development of the system started from choosing the right actuators. As mentioned, the authors choose to use in-wheels motors to eliminate the power transmission elements. The active elements of DMSVS are two in-wheel brushless DC (BLDC) motors recovered from a hoverboard. According to public information, the in-wheel BLDC chosen for this application has a diameter of 147mm without tire and 165 mm with tire, a voltage of 36 V and develops a power of 350 W at 800 rpm. [4]

Because not all technical characteristics for the hoverboard engine were available the first step in DVMSV development was to determine if the chosen engine could provide enough torque to overcome the load and inertia of VirtuSphere. Therefore, the motor's characteristics were experimental determinated and calculated through a series of practical experiments, as well as MATLAB-Simulink simulations.

First experiment determined the speed. To do so, the motor was connected to an oscilloscope and measured the frequency of 182.5 Hz, which translated into a maximum speed of 405.5 rpm, as shown in equation (1).

$$182{,}5/27 * 60 \ = \ 405{,}5 \qquad (1)$$

, where 27 is the number of poles and 60 sec/min.

Next it was determined the torque and specific characteristics of BLDC motors. For this were used equation known in the literature as in (2 – 6):

$$T = F * r = \ 200{,}74 * 0{,}0825 = 16{,}56\ Nm \qquad (2)$$

$$\mathrm{k_V} = \ \mathrm{RPM/V} = \ 11{,}12 \qquad (3)$$

$$\mathrm{k_t} = \frac{30}{\pi * \mathrm{k_V}} = 0{,}85 \qquad (4)$$

$$\mathrm{k_b} = \frac{1}{\mathrm{k_v}} = 0{,}09 \qquad (5)$$

$$\mathrm{T} = \frac{\mathrm{k_t}(\mathrm{V} - \mathrm{k_b} * \omega)}{\mathrm{R_m}} = 46{,}76\ \mathrm{Nm} \qquad (6)$$

, where T = torque at motor shaft, F = force, r = radius and

k_V = engine constant (not to be confused with kV – kilovolt)
k_t = torque constant
k_b = electromotive voltage constant
R_m = internal resistance of the motor
ω = engine rotation $[rad/s]_{SI}$

These equations together with the functional equations of a BLDC engine were included into a MATLAB/Simulink model shown in Fig. 2.

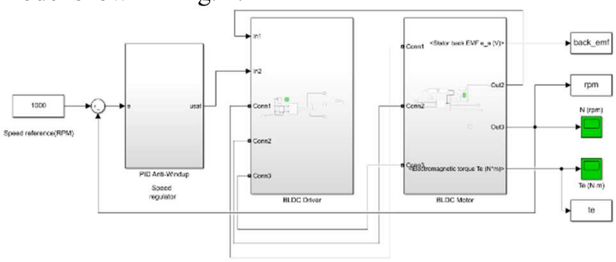

Figure 2 Simulink block model [ruse 2019]

As can be seen from Fig. 2, the functional blocks are the controller, the motor driver and the BLDC motor. To determine the optimal control method, during the simulations, controller blocks suffered modification while testing alternatives. For control were analyzed multiple types of regulators (P, PI, PD, PID, PID Anti-Windup). It was observed that classical algorithms induce nonlinear factors and decrease the system's performance and the addition of the anti-windup function increased speed reaction.

Analyzing these results, was established that PID anti-windup controller offers the best results. Results of the simulation as well as results of the real controller are presented in Fig.3. [4]

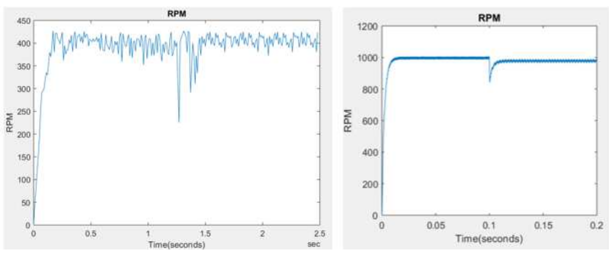

Figure 3 a) Experimental results b) Simulation results

III. Two wheels syncronisation

Drive mechatronic system for Virtusphere (DMSVS) works on the principle of trackball mouse, the wheels are training the sphere into movement. Two wheels placed perpendicular on each other on axis X and Y train the sphere like a mouse ball trains the encoder's wheels.

The scope of the system is to provide feedback to the user inside sphere corelated with VR application. In this way the feeling of immersion into VR can be improved.

A. Movement scenario

Inside sphere, the user is moving freely in any direction and this causes the sphere to move randomly. The system must synchronize the engine according to the user's movement. To gather the information a sensory system was developed by authors and it consist of 3 IMU sensors, two for feet and one for user's torso. The system provides information about the user's orientation and speed, inside sphere. The system is detailed in a different paper [5].

Multiple scenarios were identified for the sphere movement, three of which are shown in Fig.4.

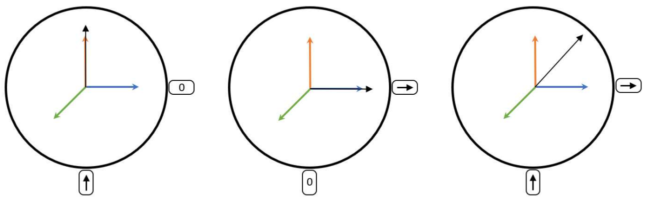
Figure 4 Movement scenario

As can be seen from Fig. 4, depending on the movement of the sphere, can be trained one or both wheels.

Considering this scenario, have been identified all possible cases based on the four quadrants of trigonometric circle. Depending on the position in the circle, the wheels are trained forward, backward or stopped.

B. Control equation

Starting from the ratio of 1: 18,18 between the wheels and the sphere calculated as in (8),

$$\frac{D_S}{D_W} = \frac{3}{0{,}165} = 18{,}18 \qquad (8)$$

where D_s= diameter sphere and D_w= diameter wheel,

for each quadrant of trigonometric circle have been defined systems of equations as in (9-12). In the following equations, θ is the measured angle and α is the calculated angle.

Case1: if θ < 90°
$$\begin{cases} \alpha = \theta \\ \omega_{M1} = \omega_S(18{,}18 \cos\alpha) \\ \omega_{M2} = \omega_S(18{,}18 \sin\alpha) \end{cases} \qquad (9)$$

Case 2: if 90°< θ <180°
$$\begin{cases} \alpha = \theta - 90^{\circ} \\ \omega_{M1} = \omega_S\,(18{,}18 \sin\alpha) \\ \omega_{M2} = -\omega_S(18{,}18 \cos\alpha) \end{cases} \qquad (10)$$

Case 3: if 180°< θ <270°
$$\begin{cases} \alpha = \theta - 180^{\circ} \\ \omega_{M1} = -\omega_S\,(18{,}18 \cos\alpha) \\ \omega_{M2} = -\omega_S(18{,}18 \sin\alpha) \end{cases} \qquad (11)$$

Case 4: if θ > 270°
$$\begin{cases} \alpha = \theta - 270^{\circ} \\ \omega_{M1} = -\omega_S\,(18{,}18 \sin\alpha) \\ \omega_{M2} = \omega_S(18{,}18 \cos\alpha) \end{cases} \qquad (12)$$

where: ω_{M1} = speed engine 1, ω_{M2} = speed engine 2 and ω_S = speed sphere.

C. *Control algorithm implementation*

For this paper, the focal point was to establish a synchronization method between the two motors based on the information received from sensory system. The sensory system has two IMU sensors on the feet that provides information about the user's speed inside sphere. The information about user orientation is received from the IMU placed on the torso. Together the three sensors represent the entrance for the control algorithm. A logic diagram is presented in Fig. 5.

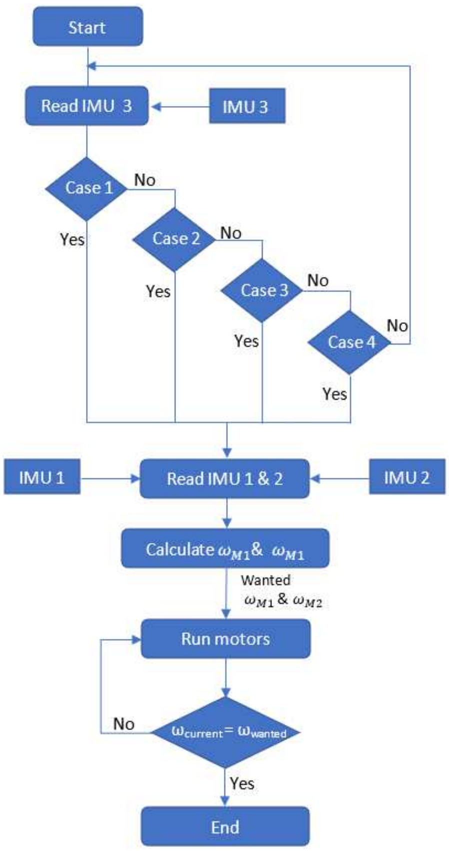

Figure 5 Control algorithm diagram

To determinate the case, the angle θ is measured by the sensory system and control algorithm decide in which case to go. Based on θ, the controller determinates in which quadrants of trigonometric circle the sphere is, and in which direction to train the motors (forward or backward). Then the angle α is caculated and replace in the equations systems.

In order to calculate the motors speed, it is needed to determinate also the sphere speed ω_S. To determine ω_S a series of calculus is needed.

We know that $V = \dot{d}$ and that the circumference of the circle is 2πR. Knowing the user speed, we can calculate the distance traveled by the user inside the sphere. Using the relationship between the distance traveled inside sphere and the circumference, it can be calculated the sphere's speed needed to ensure that distance. This speed is determinated in rpm and then converted into m/s.

Having the case selected based on IMU3 information, the sphere speed ω_S is replaced by control algoritm into the ecuations.

The last part of the control algorithm is to verify if the current motor speed is equal to the desired speed.

Since the objective of this paper is to find an optimal control strategy to syncronise the two motor, this step was verified visualy with a markers plased on sphere. For DMSVS system, this step will be completed based on information received from VR system (an optical sensor underneath sphere and HMD).

IV. Test Results

Control strategy based on switch cases has proved to be the optimal strategy. Following the tests results it was observed that, according with user orientation, the right case was always selected. Because the full DMSVS system is not yet completed and for a better observation, tests were performed with the user outside of sphere.

Based on IMU 1 and IMU 2 input, the needed motor speed was calculated correctly and verified at step "Calculate ω_{M1} & ω_{M2}". According to motors encoders, the speed was regulated and the motors achieved the desired speed.

Although the control strategy and PID controller achieved the desired results, a series of perturbation were noticed. These perturbations are difficult to measure, and so, the authors propose different solution to solve them.

For the first tests performed on the DMSVS functionality, the in-wheel motors were placed on the metallic support of the sphere. Because the sphere is made out of multiple elements joint together, this aspect is causing an uneven surface. Having the wheels placed directly on the metallic support had a disadvantage, namely: the wheel did not have the same level of contact with the uneven sphere causing either friction or sliding.

To overcome this issue, it was designed a new placement system for the wheels. The new design was inspired from a clutch and was designed in Solidworks and is shown in Fig. 6.

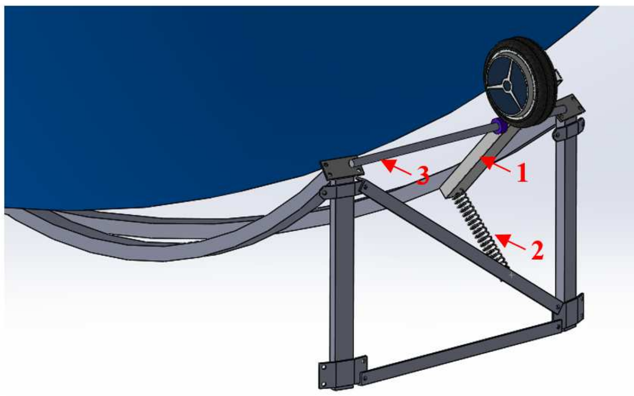

Figure 6 New DMSVS support system

The new system is designed to be part of the existing support of the sphere and it was mounted with special grip. The real system is presented in Fig. 7.

Figure 7 New placement system for the wheel

As mentioned, the sphere is formed out of multiple pieces which forms an uneven surface, this is resolved by the spring (reference 2) that will pull the swingarm to press the wheels on the sphere and have a better adherence at any time. The swingarm (reference 1) is mounted on a shaft (reference 3) which allows a precise positioning but also the balancing of the swingarm. This new system is mounted with a special grip so that the metal support of the sphere is not damaged. Because the wheels must be placed at exactly 90°, the new system allows the angle to be measured more accurately.

Apart from the problem of adhesion, it was also observed during tests, that when one wheel was actuating the sphere, the other one was opposing the movement, causing supplementary frictions. To overcome this issue the wheels have been redesigned into omnidirectional wheels. The omnidirectional wheel has an advantage over the classic tire, it does not oppose the movement.

DMSVS concept with new wheel design is presented in Fig. 8 and studies with regard of the new wheel have been already published at [6 – 9].

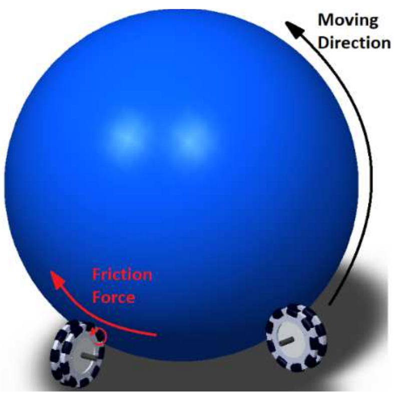

Figure 8 New DMSVS wheels design [ICATE 2020]

Because for the issues observed during the tests performed on the DMSVS with two wheels could not be found solution on the market, such as omnidirectional in-wheel motor or the wheel placement, design for DMSVS was made by authors from scratch.

CONCLUSIONS

Design of DMSVS was a challenge for the authors starting from choosing the right actuators and the optimal control strategy until finding solutions to overcome the sphere unevenness and the friction.

The scenarios identified for the sphere movement were covered by chosen strategy and the algorithm developed had fulfilled the requirements for this stage of DMSVS system.

This article presents the strategy for controlling the DMSVS system and two solutions to overcome the issues observed during tests. Because the focus for this paper was motors synchronization and not the integration with VR, the target was achieved.

Next step in development of the full DMSVS system is represented by integration with VR, as well as tests performed with user inside sphere.

ACKNOWLEDGMENT

This work was supported by the grant POCU380/6/13/123990, co-financed by the European Social Fund within the Sectorial Operational Program Human Capital 2014-2020.

REFERENCES

[1] N. Skopp, D. J. Smolenski, M. J. Metzger-Abamukong, A. Rizzo, G. Reger, “A Pilot Study of the VirtuSphere as a Virtual Reality Enhancement”, January 2014, International Journal of Human-Computer Interaction 30(1), DOI: 10.1080/10447318.2013.796441

[2] W. E. Marsh, T. Kluss, C. User, “Intent in a Virtusphere”, Conference: CHItaly 2015, 11th Biannual Conference on Italian SIGCHI ChapterAt: Rome Volume: ACM New York, NY, DOI: 10.1145/2808435.2808459

[3] E. Medina, R. Fruland, S. Weghorst, “Virtusphere: Walking in a Human Size VR "Hamster Ball"”, September 2008Human Factors and Ergonomics Society Annual Meeting Proceedings 52(27):2102-2106, DOI: 10.1177/154193120805202704.

[4] B. Lidia-Cristina, R. Horatiu, R. Ionut-Cristian and B. Nicu-George, "Study regarding improving of full immersion for VirtuSphere system," 2019 29th Annual Conference of the European Association for Education in Electrical and Information Engineering (EAEEIE), 2019, pp. 1-6, doi: 10.1109/EAEEIE46886.2019.9000467.

[5] L.C. Bazavan, H. Roibu, S.I. Cismaru and N.G. Bizdoaca, “Desing of a new sensor architecture for mechatronic systems interconnected with virtual environments”, 45th International Convention on Information, Communication and Electronic Technology - Robotics Technologies and Applications Conference 2022, unpublished.

[6] C. Wu, Z. Qiu, Y. Wang, P. Hsu and C. Hwang, "Modeling of a spherical robot driven by Omni wheels," 2011 International Conference on Machine Learning and Cybernetics, 2011, pp. 1256-1260, doi: 10.1109/ICMLC.2011.6016887.

[7] Chia-Wen Wu and Chi-Kuang Hwang, "A novel spherical wheel driven by Omni wheels," 2008 International Conference on Machine Learning and Cybernetics, 2008, pp. 3800-3803, doi: 10.1109/ICMLC.2008.4621067.

[8] S. -M. Lee, K. Xia and H. Son, "Robust Tracking Control of Spherical Motion Platform for Virtual Reality," in IEEE Transactions on Industrial Electronics, vol. 68, no. 1, pp. 892-901, Jan. 2021, doi: 10.1109/TIE.2020.2992001.

[9] B. Lidia-Cristina, R. Horatiu and B. Nicu-George, "Design of improved mechatronic system for Virtusphere," 2021 International Conference on Applied and Theoretical Electricity (ICATE), 2021, pp. 1-4, doi: 10.1109/ICATE49685.2021.9464938.