The Modeling, Construction and Test Process of a 3D Printable Smart Robot Rider

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Abstract: This work aims to present a modeling procedure, manufacturing process, electronic design, programming and communication system of a cyclist robot. The robot rider has the ability to ride a bicycle independently by making decisions on shifts in balance that may occur during its motion by correcting its direction, balance adjust, and stop. Robot decision-making processes were embedded in a shared control system of interactions with the external environment by commands sent through wired serial link or radio frequency(RF), allowing arm and leg- movements. This was achieved using a dual board synchronization powered by Atmel micro-controllers (Arduino) and fed by information from an electronic gyroscope sensor, an accelerometer, and remote radio frequency (RF) receptor. The final prototype was able to pedal from inertia accelerating gradually to its full speed, stop the movement, and move its arms to recover balance.

1 INTRODUCTION

The possibilities of autonomous bicycles and self-controlled or shared controlled robots able to maneuver vehicles have been explored for years (Getz and Marsden, 1995; Buss, 2000). It can be considered a theme driven by urban mobility needs, reduction of human physical effort and aiding people with disabilities. Moreover, modern urban mobility demands echo applications also motivate the green solution for living in large cities. Thus, increasing capacity of robots moving similarly to humans is essential for this purpose.

One of the main goals in Robotics is the automation of tasks done by men (Pazos, 2013). Thus, one of the goals in the field of Robotics is to perform simulation of variety of movements, decision making, hence human tasks performance. Despite intense research activity, large scale implementation of such tasks for daily life routine were not feasible in the early robotics, due to high cost and early development of auxiliary technology, causing to the field a moderate development outside of industrial applications.

Moreover, development of such robotic systems requires multidisciplinary knowledge. This work involved mathematical modeling, mechanical drawing, manufacture techniques in 3D printing, electronic design, micro-controller programming (Arduino, 2015; Banzi, 2013) as well as access to auxiliary devices including gyroscope, accelerometer, and RF system.

1.1 The Need for Autonomous Vehicles and Free Space

In many urban areas, human effort can be measured by the time spent on daily transit, from home to work and vice-versa. Let the distance of 1km be the initial reference to this example. In numerous cities, the urban traffic flows under the average speed of 15km/h, a cyclist can also perform the same speed, and a pedestrian, which speed is about 3km/h, would take 20 minutes to perform the same 1km task. On a daily basis, time is a precious resource and should be spent wisely . However, in rush hours (from 5 p.m. to 7 p.m.), for instance, places such as Brasilia, Brazil, a car runs at 12km/h only which means that it takes 5 minutes to perform the 1 km distance. Now, at 1 hour frame, a bicycle, with the above average speed, would make 15km, while the car, only 12km in Brasilia, re-

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sulting in a delay of 15 minutes from a car to a cyclist who would have performed 15km for the same 1 hour. In addition, in cities such as Sao Paulo, where the recorded average speed was below 8km/h, a bicycle could outperform a car by 1 hour. The result is one hour less of physically and mentally effort that could be avoided when a bicycle is used (Lopes et al., 2018).

Although bicycles are great candidate for enhancing urban mobility, the very action of balancing on a two wheel vehicle is not an easy task, even for someone with no physical or mental disability. Depending on the motor and sensory limitations of a person, the task of riding a bicycle becomes even harder, if not impossible. Additionally, a regularly used road lane can be used safely by 6 bicycles and the space needed for parking a bicycle takes one fifth of the amount of space of a car. Furthermore, automobiles cost on average 10 to 50 times more than bicycles.

The bicycle is invaluable, yet is presents a complex challenge to solve in robotics, specifically in combination with a humanoid rider. However, success in this project could possibly result in a new way of transporting people, animals, and goods.

2 RELATED WORK

Over recent decades, the research on bicycle modeling resulted in many mathematical models of balance and trajectory systems (Getz and Marsden, 1995). The model validation is another task, performed by analytic process and simulation to select the most relevant model parameters (Buss, 2000). For instance, (Buss, 2000) suggests torque and energy conservation as parameters to be part of simulation. It increases simulation confidence, given that, these parameters may be used to determine the system's stability for both cyclist and bicycle (Getz and Marsden, 1995).

2.1 A Model for Rigid Bodies

During simulation phase, both cyclist and bicycle may be represented in several means to reduce irrelevant features. For example, (Getz and Marsden, 1995) consider mass m and its height from the bicycle, row angle α, direction angle from x axis, distance b between wheels, handle bar angle ϕ and its inertia J, and a force μ which according to Getz simplifies the model.

2.2 System Dynamics

Previous projects have often used Lagrange and Euler-Lagrange methods (Sharma and Umashankar, 2006) to describe movements of a bicycle with Denavit-Hartenberg algorithm for the joint connections of the bicycle. According to (Yetkin and et al, 2014) Lagrange's equation describes energy conservation defined as

$$L = T - U \tag{1}$$

where T is the kinematic energy and U is potential energy of the system. Another research used Newton-Euler and Kane equations and virtual work principle (Shin and Lee, 2004). These methods, however, are applied with simplification and restrictions leading to difficulties to reach acceptable results in real time (Umashankar and Sharma, 2006).

2.3 Proposals without Artificial Intelligence

The majority of proposals without artificial intelligence contributed to the field by exploring which variables are more relevant to the dynamic model of a bicycle. The robot system used in (Yamaguchi, 2013)model has a remote control trajectory and PID control system (Yamaguchi, 2013)) powered PRIMER-V2 model (39cm height) by assisting its initial movement, its balance on the bicycle, and the brake action. The system required a remote control to determine its trajectory.

Most research seeks to solve both balance and trajectory control challenges. Another end-goal is developing an anti-collision system and a quality measurement system of the road where the bicycle passed (Stasinopoulos et al., 2015). In some cases, researchers try to solve both problems of balance and trajectory only through validation on simulations (Sharma and Umashankar, 2006), (Bickford and Davison, 2013), while other groups also built prototypes in different scales.

(Yetkin and Ozguner, 2013) added to their model and apparatus to simulate the gyroscope principle. A disc added below the pedals axis on their model spins to control the bicycle's row angle, however, their model does not have a direction bar. The model proposed by (Bickford and Davison, 2013)presents multiple closed loops. Their work follows the same path as many others who developed their work based on Langrange's method for dynamic equation and consider the bicycle only, without a rider. As in the previous research projects mentioned above, the linearity in this model presents limitations and depends on nearly constant linear velocities, while others could start from inertia (Keo and Yamakita, 2009).

Some research, in addition to simulation also built prototypes for real world tests. Among those projects, several proposals used balance control methods such as PD or PID control (proportional integral and derivative) applied to the direction bar, and gyroscope principle whether upon the the bicycle or below it together with PD control (Wang et al., 2012). There were also variable systems with linear parameter (VLP) (Cerone et al., 2010), springs(Pandey et al., 2015), and more complex systems such as slide control altogether with gyroscope principle. Those prototypes were developed, in majority, from commercial bicycles with further adaptations. However, there are also those who built their bicycles in different scales (Aphiratsakun and Techakittiroj, 2013). According to (Aphiratsakun and Techakittiroj, 2013), controlling a prototype by a micro-controller is a very difficult task.

2.4 Proposals with Artificial Intelligence (AI)

Although first models with AI have been developed at least two decades ago (Randløv and Alstrøm, 1998), there were more work with traditional controllers. On the other hand, the few number of works in AI, show how the solutions are complex among these groups as IA solutions claimed to be of simpler implementation compared to traditional controllers. (Cook, 2004)) for instance, sought demonstrating to be possible maneuver the bicycle balanced along a trajectory using only two neurons as controllers. Although the artificial neural network (ANN) approach seems to be easier, it has some drawbacks related to the number of iterations it required until the first results are achieved. Moreover, determining weight was very challenging, thus leading to error most of the time. (Randløv and Alstrøm, 1998)tried solving those issues combining reinforcement learning and calibration, yet their approach required 5700 attempts for reasonable results. Without calibration, however, it would be necessary 10^{10} attempts. (Cam et al., 2013) revisited Randløv and Alstrøm work on Python environment Panda3D (Goslin and Mine, 2004) and PyBrain support (Schaul et al., 2010). Their results had shown that the learning algorithm continuously dropped previous steps out, making it very sensitive to local minima, which prevents the algorithm's convergence for balance and travel tasks. Convergence is the global learning point for certain problems where reward is maximized while penalty is minimized.

(Umashankar and Sharma, 2006) presented an interesting method based on neuro-fuzzy adaptive control where fuzzy rules are applied upon a three layer neural network. The first layer contains inputs, the second layer has fuzzy rules, and the third layer is the output. Their model is based on Euler-Lagrange as the same presented in (Sharma and Umashankar, 2006), however, its new control provides more possibilities because of its learning capacity altogether with fuzzy rules showed to be a better option than the old method which did lose stability after ten seconds.

A complete work in computer graphics focused on the state description of a cyclist-bike system and presented a machine learning proposal for a character able to perform several stunts on a BMX model (Tan et al., 2014). In their work, it was not the bicycle that was controlled, but the cyclist by an evolutionary neural network. Due to the stunt's complexity, one cannot take into consideration bike dynamic only. Rather, cyclist and bicycle as two rigid bodies connected with six degrees of freedom using Jacobean transpose matrix. The project also simulated power transfer from feet to pedals, presenting excellent results on stunts performance during simulation. Other research applied Deep Deterministic Policy Gradient (DDPG) which is a deep learning approach to control balance and bicycle's trajectory by minimizing the system error (Chung et al., 2017).

3 METHODOLOGY

The initial phase was the creation of mathematical models for arms and legs. The final step involved the simulation of movements for arms and legs as well as the first real world test for a pedal movement and balance. The construction of the robot was designed upon the use of renewable materials such as plastic which reduced the manufacturing cost. The same plastic was also used to built the 3D printer which has refurbished pass-motors. Moreover, discarded pieces of aluminum compose the frame of the bicycle and the side shields on the legs of the robot.

3.1 Mathematical Modeling

The model followed the Homogeneous Transformation method. According to Figure 1, the robot has three actuators (shoulder, arm, and elbow) for each arm. Using the Kinematic diagram from Figure 1, the relation from shoulder to hand can be expressed by the homogeneous matrix equation in eq. 2 composed by the rotation matrix and the displacement vector.

$$H(arm)_3^0 = H(shoulder)_1^0 H(arm)_2^1 H(elbow)_3^2 \quad (2)$$

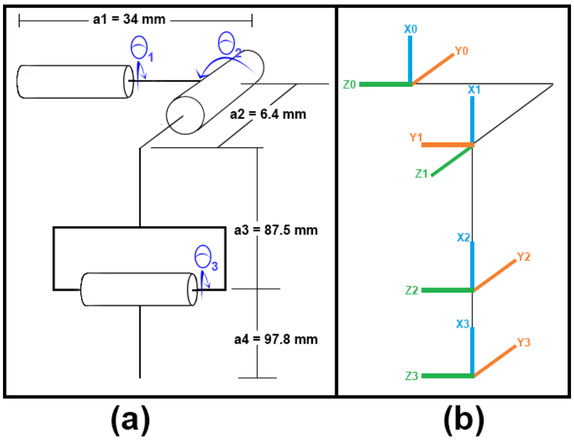

Figure 1: Arm kinematic diagram: a) link lengths ans rotation angles, b) rotation frames.

Similarly, the mathematical model for the robot leg was obtained from the kinematic diagram in Figure 2. The final homogeneous matrix expressed by eq. 3 is the hip-to-foot relation.

$$H(leg)_4^0 = H(hips)_1^0 H(thigh)_2^1 H(knee)_3^2 H(ankle)_4^3 \quad (3)$$

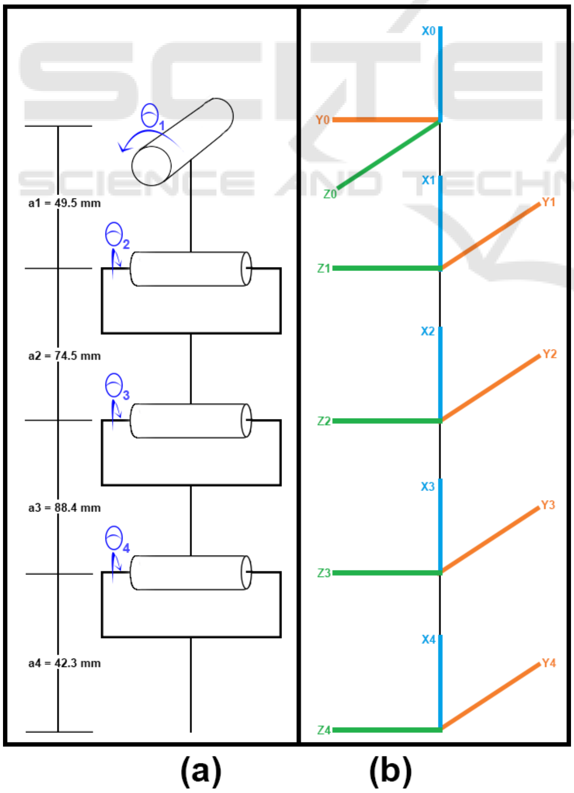

Figure 2: Leg kinematic diagram, a) link lengths and rotation angles, b) rotation frames.

3.2 Mechanical Structure: Hardware

3.2.1 Modeling Each 3D Part

AutoCAD was used as the main graphic tool to design the robot and bicycle. In the first stage, each part of the robot was sketched, as seen in Figure 3,and later sculpted to three dimensions. In the second stage, every part was converted to STL file format to be printed in 3D, Figure 4. Lately, the slicing were made on a Reprap 3D printer software in order to set how many layer of PLA would be used and also for time estimation to construct each part. During construction stage, tests had been performed in order to probe mechanical properties of critical parts.

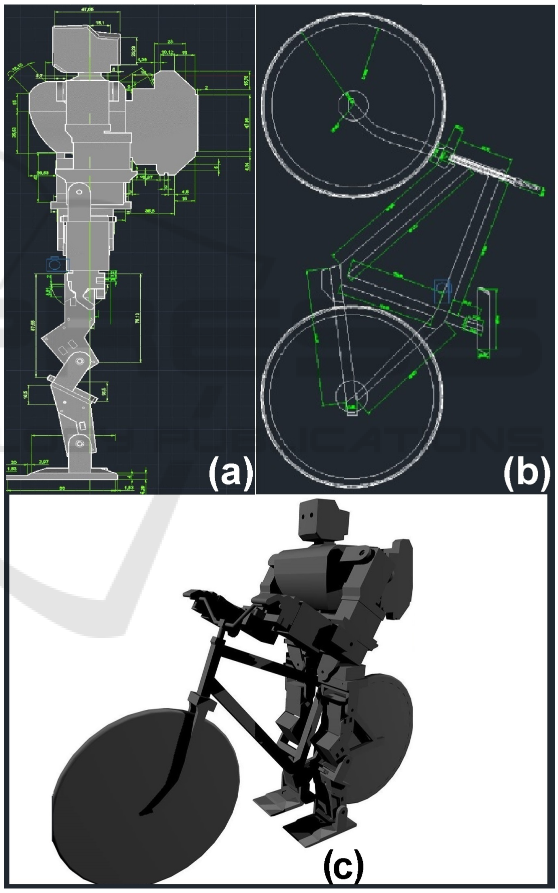

Figure 3: Robot (a) and its bicycle(b) both sketched in AutoCAD, (c) 3D model.

3.2.2 The Bicycle Construction

The acrylic wheels of the bicycle were estimated according to the robot legs with 19cm diameter, 10mm in thickness, and central hole of 1mm diameter. The tire of each wheel was made of EVA tape(2.5 mm

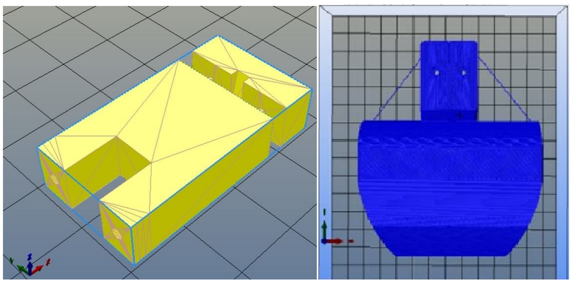

Figure 4: Parts in the printing process servo's socket on the left and the slicing process on the right.

thick). This tape has the purpose to increase grip between the wheel and the ground, and it also reduces vibration on the composition. The main structure of the bicycle is made of square bars of aluminum 6cm thick, blend by aluminum soldering. A tripod was manufactured to support the bicycle balanced during tests. The transmission systems was built with a sew machine rubber chain, connecting the 3D printed gears of the bicycle. Pedals were challenging, for it was made by using spin socket of an orthodontic machine had been couple on an 1.5mm diameter axis to smooth movement and reduce grip.

3.2.3 The Power Supply

We used a specific battery of a hospital apparatus (pulmonary apparatus) to provide adequate currents and voltages for the entire circuit and motors. This battery contains a circuit with fuses of protection against surges, under voltages and thermal fuses for monitoring the temperature. We also manufactured a board able to perform pulse width modulation (PWM). Is was composed of a voltage regulator of 11V to 5V and a current limiter of 7A to 3A to supply suitable for the robot. The board contains four 2n3055 voltage regulators and Zener diode for 6V voltage reference.

3.3 The Automated System Proposal

The algorithm was developed in C++ and deployed in Arduino board Nano 3.0 with supporting libraries servo.h and IR.h for servos' control (Cormen and et al, 2002; Sedgewick, 1998). Figure 5 show the flowchart for the algorithm developed. The data from gyroscope collected through serial protocol RS232 was used to calibrate the end angles of motion.

3.3.1 Detailed Movement

During the tests, the robot rider was able to perform basic movements, such as pedaling, holding its feet on the ground while riding, and moving its arms according to the feedback from the accelerometer. We divided the robot's movements into stop mode and motion. When it is in stop mode, the robot holds its feet on the ground. In the transition from stop to motion, one foot is set to back position prior to pedaling, which means the other foot remains the right position to impulse the robot and overcome the inertia. In intial tests, the arms stayed stretch horizontally during real world tests a T-shape with the body. The acceleration of the robot either increase speed or slow down helping synchronization of both legs during the required movements. When the robot starts the transition from movement to complete stop, it decelerates and takes both legs off of the pedals stretching them to touch the ground. Both movements, pedaling and stopping can be remotely set.

Another featured movement built in the algorithm is the emergency stop. When the gyroscope presents skewed data, it triggers the movement, which indicates that the robot may be falling. Thus, when the algorithm detects this situation, the robot halts its pedal function to enter in emergency mode, stretching the arms and the legs.

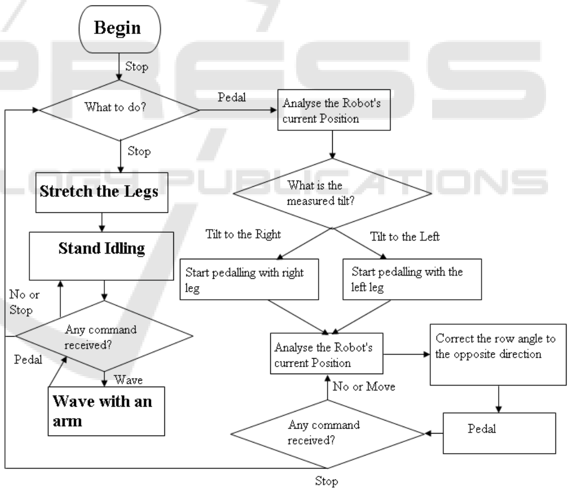

Figure 5: Algorithm's flowchart demonstrating the decision steps the robot may take.

4 RESULTS

4.1 The 3-D Printing Phase

4.1.1 Process of 3D Printing

The majority of the parts of the robot (approximately 70%) were made by 3D printing. The 3D printers were also assembled using reusable materials. It works with plastic wires (3 mm or 1.75mm) made of polylactic acid (PLA)which is melted to make the layers of the 3D printed parts.

After every part was finished by the printer, it was measured in order to check if its dimensions would met the designed project. Symmetry, and layer size were measured. Some parts which should be coupled to servomotor had density increased by 90% in order to bear forces applied to them. Other parts were redesigned for their size were not feasible to be printed as a single piece or they had inner connections that would not able accessed such as chest, battery case, and head). Because of lack of precision for small parts, some parts had to be adapted, such as the hands.

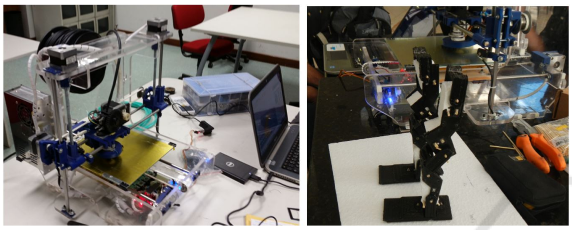

Figure 6: Printer and the first prototype printed legs.

4.2 The Assembling Process

A total 15 servo motors of 13N each with were used to move all members of the robot. This phase involved 40% of the project budget. The servo motor were also disassembled to add a 3mm steel axis to the opposite side the servo axis.

4.2.1 The Bicycle Assembling

In the process of construction of the bicycle, we used a 5mm solid aluminum bar to let the robot lighter and balance the weight / power ratio. TIG welding was used to reinforce the frame and with center of gravity for the suitable robot. The wheels are made of acrylic of 10 mm which were cut using the laser process to stay closer to the CAD model.

After the assembling phase was complete, the prototype, as well as its remote control, as shown in Figure 7, were ready for testing.

4.3 Simulation and Tests

Legs were tested to check their movement while pedaling. Tests had shown a balanced structure and well synchronized servomotors. After first tests, current measurements had shown consumption of 1.2A for each leg, in which every servomotor consumed 400mA. On a standby state the robot consumed 370mA.

Table 1: Time spent on manufacturing each part of the bike rider.

QUANTITY	COMPONENT	TIME
01	neck	36min
01	finger 1	47min
01	finger 2	47min
02	shin	1h 26min
01	foot 1	1h 49min
01	foot 2	1h 49min
01	neck base	1h 50min
02	thigh socket	2h 25min
02	ebow socket	2h 26min
02	ankle socket	2h 26min
02	forearm socket	2h 26min
02	knee base	2h 42min
02	foot base	2h 46min
02	elbow base	2h 51min
01	waist top	2h 54min
01	waist link	2h 57min
02	knee	3h 4min
02	foot socket	3h 4min
02	thigh	3h 11min
02	knee socket	3h 42min
02	femur socket	4h 4min
01	hand 1	4h 10min
01	hand 2	4h 10min
02	acrylic knee	4h 13min
02	forearm	4h 38m
02	waist socket	4h 43min
02	head	4h 44min
01	hips base	5h 4min
01	battery case 2	5h 7min
01	battery case 1	8h 31min
01	waist	8h 44m
01	hips	8h 48min
01	back	14h 42min
01	chest	22h 1min
51	TOTAL	149h 37min

The first pedaling movement had to have fine tuning on tilt coupling, angular speed on each servomotor and low rotation setup to perform the desired movement.Figure 8 shows that the movements produced by the system had a squared pattern,requiring additional fine-tuning.

The algorithm cost required two Arduino boards (salver and master) to slpit the legs routines from the signals to the arms. A status signal allows the master to know if the other Arduino is on stop mode, movement, or whether an error occurred. Moreover, the master board also receives the remote commands from the joystick. When the system is ready, the mas-

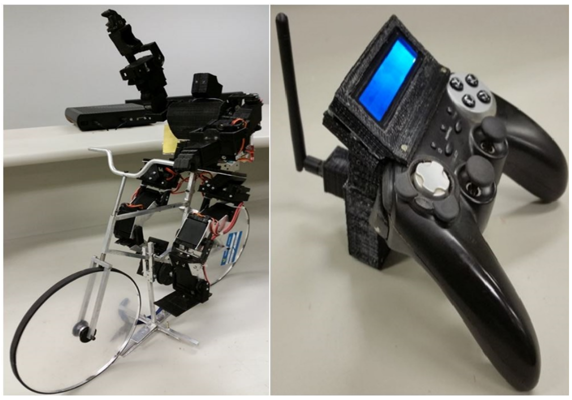

Figure 7: Assembled robot (second prototype) and joystick remote control.

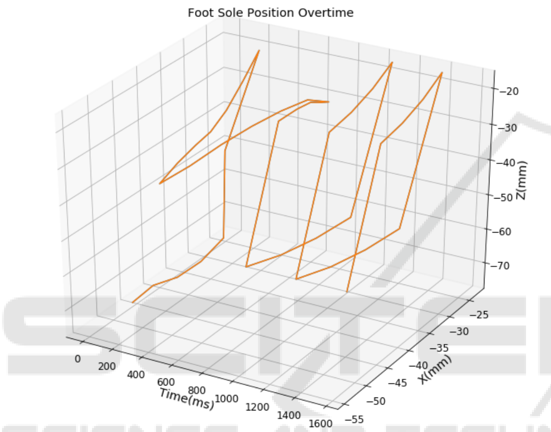

Figure 8: Foot movement simulation based on hip-to-foot displacement vector.

ter Arduino set all initial parameters on the slaver board to avoid code redundancy. After all parameters set, the slaver board flags back a ready signal to the master board. The communication between both Arduinos allows the master to send stimuli signals to the slaver board when it is in movement mode. When it is in stop mode however, the master board sends only one stop signal. If the master board stops working and the salver board is in movement mode, as it will not receive the next stimuli, the emergency mode will be triggered when the time for the next stimulus is over. On the other hand, if the slaver Arduino board stops working, the master board will notice it by the status signal as it stopped receiving from the salver board. Therefore, the master board will immediately reset its own status and will keep trying to reestablish the link with the other board until it succeed. After reestablishing the link, the master board sends again the initial parameters to the salver board.

In the simulation phase, the arms was in bent position, with hands holding the steering bar as presented on Figure 9.

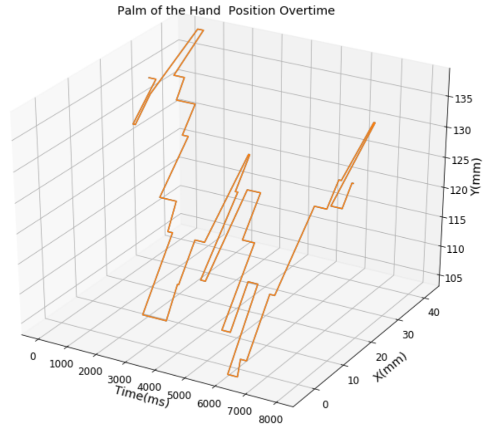

Figure 9: Palm of the hand movement expressed by shoulder-to-hand displacement vector.

5 CONCLUSIONS

This work presented the process of modeling, design, construction and test of 3D printable robot rider. The algorithm developed in C++ enable robot to move its arms and legs to perform desired actions such as pedaling, turning direction bar, start, and stop movements. The mathematical model proved to reach the proposed movement, although it required fine tuning to smooth the movement.

All parts of the bike rider were designed to fit the servomotors. In order to a better performance, a second Arduino board had to be added to split the movements from legs to arms.

Future work will include a free run test without a tripod that supported the initial test of the robot.Moreover, a forward kinematic system based on neural network can also be compared to the current algorithm.

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REFERENCES

Aphiratsakun, N. and Techakittiroj, K. (2013). Autonomous au bicycle: Self-balancing and tracking control(ausub^2). In *IEEE International Conference on Robotics and Biomimetics(ROBIO)*.

Arduino, S. A. (2015). Arduino. *Arduino LLC*.

Banzi, M. (2013). *Primeiros passos com o arduino (First steps with arduino)*. Novatec, Sao Paulo, 1st edition.

Bickford, D. and Davison, D. (2013). Systematic multi-loop control for autonomous bicycle path following. In *2013 26th IEEE Canadian Conference on Electrical and Computer Engineering (CCECE)*, pages 1–5. IEEE.

Buss, S. R. (2000). Accurate and efficient simulation of rigid-body rotations. *Journal of Computational Physics*, 164(2):377–406.

Cam, B., Dembia, C., and Israeli, J. (2013). Reinforcement learning for bicycle control.

Cerone, V., Andreo, D., Larsson, M., and Regruto, D. (2010). Stabilization of a riderless bicycle: A linear-parameter-varying approach. In *IEEE Control Syst. Mag*. Citeseer.

Chung, T. et al. (2017). In *2017 14th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI)*, pages 413–417. IEEE.

Cook, M. (2004). It takes two neurons to ride a bicycle. *Demonstration at NIPS*, 4.

Cormen, T. and et al (2002). *Algoritmos: teoria e prática (Algorithms: theory and practice)*. Elsevier, Rio de Janeiro, 2nd edition.

Getz, N. H. and Marsden, J. E. (1995). Control for an autonomous bicycle. In *Proceedings of 1995 IEEE international conference on robotics and automation*, volume 2, pages 1397–1402. IEEE.

Goslin, M. and Mine, M. R. (2004). The panda3d graphics engine. *Computer*, 37(10):112–114.

Keo, L. and Yamakita, M. (2009). Controller design of an autonomous bicycle with both steering and balancer controls. In *2009 IEEE Control Applications,(CCA) & Intelligent Control,(ISIC)*, pages 1294–1299. IEEE.

Lopes, R. R., Monteiro, L. S. G., de Miranda, R. R., and de Souza Carvalho, C. (2018). (relatório anual de acidentes de trânsito - 2017 (annual report on traffic accidents - 2017). Technical report, The Traffic Engineering Company (Companhia de Engenharia de Tráfego).

Pandey, A., Mahajan, S., Kosta, A., Yadav, D., Pandey, V., Sahay, S., Jha, S., Agarwal, S., Bhise, A., Kumar, R., et al. (2015). Low cost autonomous navigation and control of a mechanically balanced bicycle with dual locomotion mode. In *2015 IEEE International Transportation Electrification Conference (ITEC)*, pages 1–10. IEEE.

Pazos, F. (2013). *Automacao de Sistema e Robotica (System Automation and Robotics)*. Axcel, Sao Paulo, 1st edition.

Randløv, J. and Alstrøm, P. (1998). Learning to drive a bicycle using reinforcement learning and shaping. In *ICML*, volume 98, pages 463–471.

Schaul, T., Bayer, J., Wierstra, D., Sun, Y., Felder, M., Sehnke, F., RĆ1/4ckstieĆ, T., and Schmidhuber, J. (2010). Pybrain. *Journal of Machine Learning Research*, 11(Feb):743–746.

Sedgewick, R. (1998). *Algorithms in C: parts 1-5*. Addison Wesley Longman, New York, 3rd edition.

Sharma, H. D. and Umashankar, N. (2006). A robotic model (robi) of autonomous bicycle system. In *2006 International Conference on Computational Inteligence for Modelling Control and Automation and International Conference on Intelligent Agents Web Technologies and International Commerce (CIMCA'06)*, pages 107–107. IEEE.

Shin, J.-C. and Lee, C.-W. (2004). Rider's net moment estimation using control force of motion system for bicycle simulator. *Journal of robotic systems*, 21(11):597–607.

Stasinopoulos, S., Zhao, M., and Zhong, Y. (2015). Human behavior inspired obstacle avoidance & road surface quality detection for autonomous bicycles. In *2015 IEEE International Conference on Robotics and Biomimetics (ROBIO)*, pages 2121–2126. IEEE.

Tan, J., Gu, Y., Liu, C. K., and Turk, G. (2014). Learning bicycle stunts. *ACM Transactions on Graphics (TOG)*, 33(4):50.

Umashankar, N. and Sharma, H. D. (2006). Adaptive neuro-fuzzy controller for stabilizing autonomous bicycle. In *2006 IEEE International Conference on Robotics and Biomimetics*, pages 1652–1657. IEEE.

Wang, L. X., Eklund, J. M., and Bhalla, V. (2012). Simulation & road test results on balance and directional control of an autonomous bicycle. In *2012 25th IEEE Canadian Conference on Electrical and Computer Engineering (CCECE)*, pages 1–5. IEEE.

Yamaguchi, M. (2013). Cyclist robot able to ride a bicycle (original title in japanese). $http://ai2001.ifdef.jp/primer\_V2/primer\_V2.html$. Accessed on January 14, 2019.

Yetkin, H. and et al (2014). Gyroscopic stabilization of an unmanned bicycle. In *American Control Conference*.

Yetkin, H. and Ozguner, U. (2013). Stabilizing control of an autonomous bicycle. In *Control Conference (ASCC)*.