STUDY ON SELF BALANCING MOTORCYCLE USING THE CONCEPT OF REINFORCEMENT LEARNING

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Abstract - *Motorcycle is a very popular transport due to its energy efficiency, compact design, convenience and an attractive look. Despite the features and popularity, motorcycles lack safety and are very risky. There is a high chance for road accidents since the passenger's body is directly exposed during the ride. Therefore, motorcycle accidents are fatal. Balancing any two wheeled vehicle is always a challenging task for both humans and robots from a long time. The biggest problem for most two-wheeler riders is to keep the vehicle balanced. Losing balance happens almost everyday and people hate the leg-up, leg-down exercise that we end up doing thousands of times in heavy traffic. To establish this machine learning phase with embedded systems, we proposed a system to balance a motorcycle that can minimize damages in case of any impact. Our system aimed to design a self-balancing Motorcycle or otherwise called a 'MOTOBOT' using the technique of Reinforcement Learning. Basically, the system would be a bicycle bot powered by an electric motor. The two wheeler vehicle would be able to balance itself and could be stabilized against any impact, The vehicle will contain an additional momentum wheel or an inertia wheel, which would probably be placed at the center of the vehicle. The Self-balancing is achieved by rotating the inertia wheel at various angles. The vehicle would balance itself by using a counter force action when the inertia wheel tilts beyond the accepted angle. The proposed system would be of great help for people with certain disabilities, youngsters and adults who have never learned to ride a bicycle and people suffering from developmental or cognitive disabilities*.

KeyWords: **Self balancing Motorcycle, Reinforcement Learning, Momentum Wheel, Pybullet Simulator, Deep Q-learning Algorithm.**

1. INTRODUCTION

With the increase of environmental awareness, research into transportation methods that use alternative energy have been on the rise over the past few years. The Segway is one example: it greatly reduces noise and air pollution, while its high mobility allows it to access most public spaces. However, a two wheeled vehicle does not possess the same mechanical stability as a four wheeled vehicle. The special nature of the two wheeled design places it in a non-linear and unstable environment, where a self balancing control system is required to maintain a balanced state. The two-wheeled self-balancing robot has become a subject in verifying various control theories since it occurred, which is mainly due to its unstable dynamic performance and strong nonlinearity. A system that could provide balancing assistance to a motorcycle rider could be more useful to many people in these times.

1.1 Background

The background theory behind the Self balancing Motorcycle is similar to that of balancing an Inverted Pendulum, which has its mass above its pivot.The upright position is an unstable equilibrium for the inverted pendulum and must be actively balanced to remain upright. For example, the human body is an inverted pendulum balancing the upper body around our ankle joints in every step. In the recent decade Segways, making use of bodily movements for steering, have emerged on the market. In common, these applications share that their centre of mass is located above their pivot points, thus requiring active control in order to balance. A self-balancing motorcycle that maneuvers itself on varying terrain and remains upright using an momentum wheel placed at its center.

1.2 Reinforcement Learning

Reinforcement learning[9] is the iterative process of an agent, learning to behave optimally in its environment by interacting with it. The way the agent learns to achieve a goal is by trying different actions in its environment and receiving positive or negative feedback, also called exploration. In the context of the self-balancing motorcycle, the agent will be the motor controlling the momentum wheel. The way it interacts with its environment is by spinning the wheel at different speeds, and the feedback it receives is the current position and angular velocity. Positive and negative feedback is determined by a unique reward function.The key factor in any reinforcement learning application is the reward function that is being maximized. To optimize the learning, the reward function provides positive reward for actions that help attain the goal and negative reward for actions that hinder the bike from attaining its goal.

The self balancing would be achieved using the reaction wheel or inertia wheel(momentum wheel) placed at the centre of the motorcycle. Speed of a reaction wheel is increased or decreased to generate a reactionary torque about the spin axis which is parallel to the motorcycle's frame. Imagine if the motorcycle begins to fall onto one side, a motor mounted to the reaction wheel applies a torque on the reaction wheel, generating a reactionary torque on the motorcycle, which brings back the motorcycle's balance.

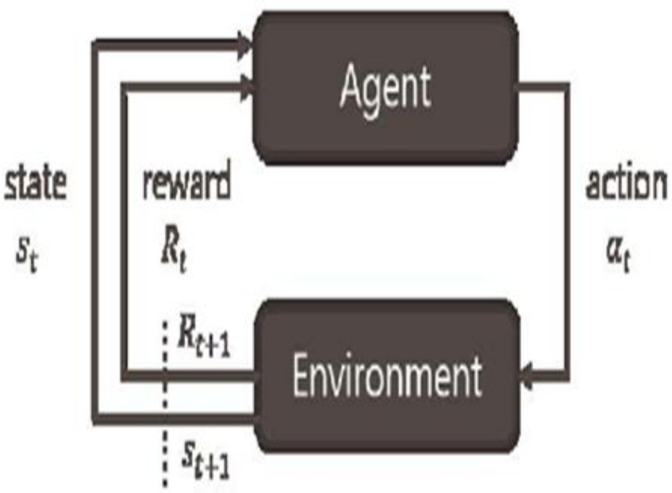

Fig -1: Reinforcement Learning

2. LITERATURE SURVEY

2.1.Segway Personal Transporter

Segway PT[11] is a two-wheeled self balancing personal transporter by Segway Inc. ,invented by Dean Kamen and brought to market in 2001. The original segway. Segway PT (referred to at the time as the Segway HT) was developed from the self-balancing iBOT wheelchair which was initially developed at the University of Plymouth, in conjunction with BAE Systems and Sumitomo Precision Products. Steering of early versions was controlled using a twist grip that varied the speeds of the two motors. The range of the p-Series was 6–10 mi (9.7–16.1 km) on a fully charged nickel metal hydride (NiMH) battery with a recharge time of 4–6 hours. Unlike a car, the Segway only has two wheels; it looks something like an ordinary hand truck yet it manages to stay upright by itself. To move forward or backward on the Segway, the rider just leans slightly forward or backward. To turn left or right, the rider turns the right handlebar forward or backward.

At its most basic, the Segway is a combination of a series of sensors, a control system and a motor system. The primary sensor system is an assembly of gyroscopes. A basic gyroscope is a spinning wheel inside a stable frame. A spinning object resists changes to its axis of rotation, because an applied force moves along with the object itself. If you push on a point at the top of a spinning wheel, for example, that point moves around to the front of the wheel while it is still feeling the force you applied. As the point of force keeps moving, it ends up applying force on opposite ends of the wheel the force balances itself out. Because of its resistance to outside force, a gyroscope wheel will maintain its position in space, even if you tilt it. But the gyroscope frame will move freely in space. By measuring the position of the gyroscope spinning wheel relative to the frame, a precise sensor can tell the pitch of an object as well as its pitch rate. Segways use a special solid-state angular rate sensor constructed using silicon. All of the tilt information is passed on to the "brain" of the vehicle, two electronic controller circuit boards comprising a cluster of microprocessors. The Segway has a total of 10 onboard microprocessors, which boast, in total, about three times the power of a typical PC. Normally, both boards work together, but if one board breaks down, the other will take over all functions so that the system can notify the rider of a failure and shut down gracefully. The Segway requires this much brain power because it needs to make extremely precise adjustments to keep from falling over. In normal operation, the controller boards check the position sensors about 100 times per second. When the vehicle leans forward, the motors spin both wheels forward to keep from tilting over. When the vehicle leans backward, the motors spin both wheels backward. When the rider operates the handlebar control to turn left or right, the motors spin one wheel faster than the other, or spin the wheels in opposite directions, so that the vehicle rotates.

Segways are also good machines for getting around crowded warehouses, where tight corridors make it difficult to use bulkier vehicles. People may find them useful for getting around large pedestrian areas, such as airports or amusement parks. There is really no limit to how people might use the vehicle. The Segway can fit in most places you might walk, but it will get you there faster, and you won't exert much energy. The gyroscope sensors and other sensors of the Segway brain are tuned manually to attain a stable state in the horizontal platform.

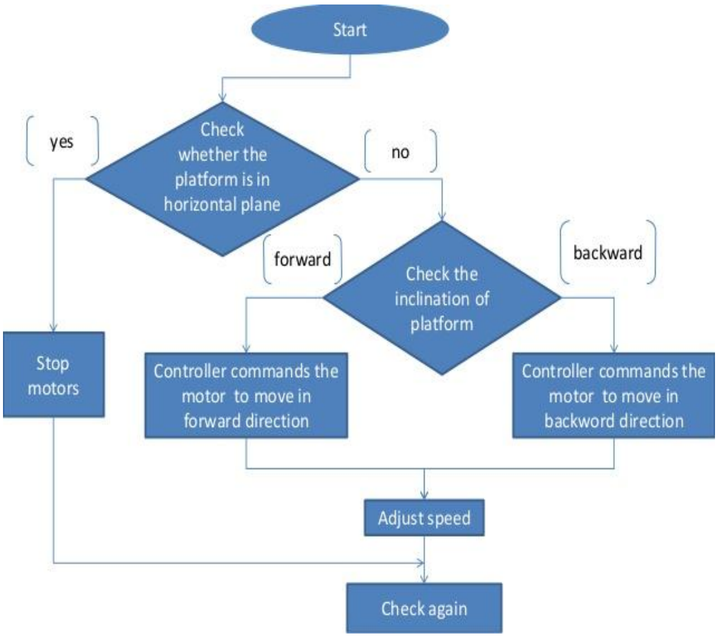

Fig -2: Segway PT Flowchart

Fig -3: Segway PT

2.2. Self Balancing Electric Scooter

Liger Mobility, a start-up incubated by IIT graduates came up with an electric two wheelers[12] that can self-balance, a technology that is yet to be commercialized by auto giants like Yamaha and Honda. While the two auto majors have shown concept motorcycles which can self-balance, this technology is not launched in any production two wheeler, since it is still in Research & Development and is very expensive. However, IIT Bombay-incubated EV startup has managed to come up with a similar self-balance technology, which is not expensive. This system can be installed in any automatic scooter. The cost of this scooter would be 10 percent of the cost of the existing scooter. This is not the first self-balancing two wheeler technology in the world but as most engineering innovations that come out of India demonstrated in the past, this one is affordable. Physically, self-balancing can be achieved by calibrating a ballast of sorts in real-time. To facilitate this, one would need a system of accurate sensors, quick actuators (like servo motors), and a robust algorithm. In addition to the obvious benefit of enhanced safety, affordable self-balancing technology for two wheelers would go a long way in making them autonomous. Till date, no vehicle has been seen in the country that a vehicle will come out automatically by your voice command. It was quite amazing and the rider can control it easily.

Fig -4: Self Balancing Electric Scooter

2.3. C-1 Self balancing Motorcycle

Lit Motors Inc. is a San Francisco-based company that designed conceptual two-wheeled vehicles called C-1 Self balancing Motorcycle[13], including a fully electric, gyroscopically stabilized vehicle. It was founded by Daniel K. Kim in 2010, Lit Motors designed concepts for two-wheeled vehicles with a focus on innovative technologies. The inspiration for Lit Motors came to Kim in 2003, when he was nearly crushed by a chassis while manually assembling a bio-diesel Land Rover Defender 90. Kim decided to "chop a car in half" to create what is now the C-1. Similar to a motorcycle, the original C-1 design has two wheels, but uses a small steering wheel instead of handlebars. The direct-drive in-hub motors in both wheels were designed to provide a high amount of torque, stability and traction control, while allowing for the body form to be about half the size of a car. Prototypes show neither wheel with direct drive and only a single person capacity, indicating that the design may be undergoing changes. Safety features were intended to include a steel unibody chassis, seat belts, airbags, and a gyroscope stability system.It is powered by the powerful, patented gyroscopic stability system, the electronically-controlled C-1 operates using Control Moment Gyroscopes (CMGs), which produce thousands of ft-lbs of torque. The car controls these gyros, which allow it to make its way sleekly in and out of narrow turns and stay upright when faced with a collision. The C-1 is a revolutionary innovation in the industry, creating new standards of car interface and safety on a two-wheeled platform.

The dynamic C-1 is designed to provide the ultimate efficiency required for high-speed travel. It was influenced by Scandinavian design, the exterior of the C-1 is both simple and approachable. This allows comfort of a compact ride and the thrill of high speed travel. Its expansive glass, subtle curves and softened volumes make it desirable and highly functional. It is powered by high-torque in-hub electric motors that save space, it provides a responsive driving experience. The C-1 regenerates energy while braking. It does so by using a KERS (Kinetic Energy Recovery System), which stores up the energy kinetically in the gyro flywheel. This dynamic ride will feature smartphone and cloud connectivity, an innovation that is unparalleled in the industry. It's powered by a small 10 kWh battery pack, the C-1 is a 100% electric ride that can travel up to 200 miles per charge. Make no mistake, this ride is ready to hit the freeway at the top speed of 100+mph, and an acceleration of 0-60 in six seconds.

Fig -5: C-1 Self balancing Motorcycle

2.4. Comparison/Analysis

Segway P T is a clean, green, eco-friendly machine while it does not exactly say how far the segway will go with riders of different masses and is expensive too.

Self balancing Scooter would be affordable to common people and pollution free while recharging the vehicle takes longer time.

C-1 Self balancing Motorcycle is 100% electric that can travel up to 200 miles per charge while charge time depends on voltage and the balancing depends on the surface.

On analysing the existing systems with the proposed system, the Motorcycle robot has the ability to quickly return to a balanced state under any dip angle using the method of reinforcement learning. Along with the motor, the robot would be equipped with an accelerometer and boost converter which helps in maintaining its balance. Using the Deep Q-Learning method, adjustments to the motor were made according to the current position and the angular velocity at that given time to return the robot to balance.

The electric controllers used in all existing system models are considered to be time consuming and have limited performance because they rely on model accuracy. These controllers may not assure the desired performance for a changing environment/ operating points.

3. SELF BALANCING MOTORCYCLE DESIGN

The design of the two wheeled self balancing robot structure contains a servo motor for the rotation of the handle and 2 stepper motors, one for the wheels and the other for the momentum wheel. It also contains an accelerometer, boost converter(step up converter) and lipo battery of about 12V.

The chosen design is the one that would work well with the parts we have and then sketched out different prototypes. Once the rough online of what the design could look like is complete, Solid works(3D CAD Design software) was used to model the first prototype. This prototype was then used to simulate the physics. The properties like the weight of the frame and the moment wheel were calculated a dozen times and simulated each result until we reached one that works. Using this result and the parts that we could buy, the final prototype was made. The frame was made small enough to be able to 3d print at the lowest cost. Solidworks helps the user to create drawing directly in 3D or solid form. The three solidworks components are Part, Assembly and Drawing. Part is defined by its sketch and selected features. Assembly is how all parts assemble in one unit. Drawing is for detailing and adding dimensions to part.

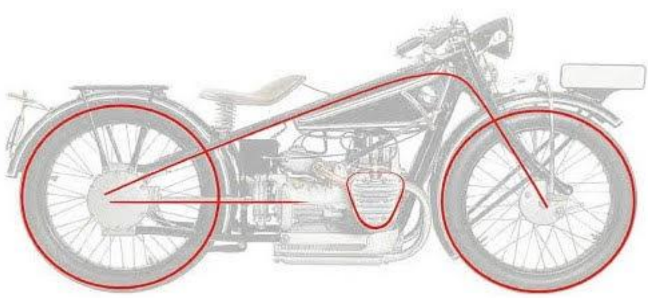

Fig -6 Motorcycle frame design for modelling

Fig-7 (a): Initial Motorcycle Frame Front view

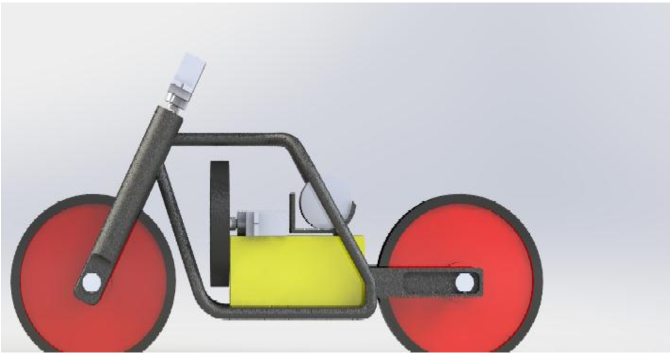

Fig-7 (b): Initial Motorcycle Frame Side view

The Final Prototype Design was made considering all the parts and their size and materials needed for assembling them together. The size of the momentum wheel and the material with which it has to be made was a major challenge in making the design.

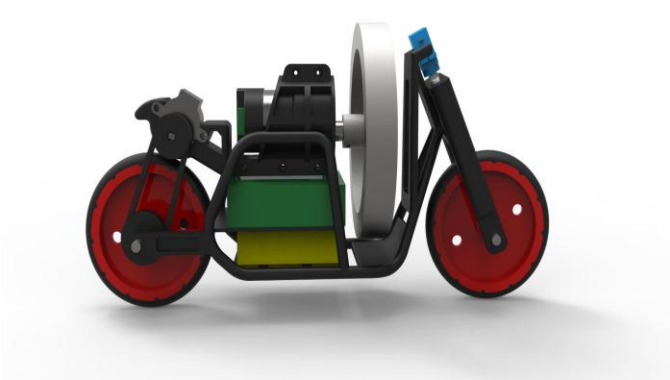

Fig-8 (a): Final Prototype Design Side view

Fig-8 (b): Final Prototype Design Front view

4. PYBULLET SIMULATOR

Simulation recreates a real world process in a controlled environment by creating laws and models to represent the world. The simulation of the 3D designed motorcycle model was done using a pybullet simulator. This simulator uses a Python module for physics simulation, robotics, visual effects and machine learning. It is easy to set up and use and includes a viewport module that has lots of visualization and interaction features built in. The model is loaded to the simulator in URDF(Universal Robot Description File)Format. The load URDF will send a command to the physics server to load a physics model from a URDF.

Firstly, the initial motorcycle frame was the model loaded into the pybullet simulator. It was then trained on the environment that we created with necessary packages. In addition, since our environment is defined by physics, PyBullet was really helpful to perform the necessary computations and visualize experiment progress.

The prerequisites to be done for performing simulation are:

(1) Miniconda3 for windows(64bit) with python version 3.6

(2) Creation of an environment for simulation

(3) Activation of the created environment

(4) Installation of necessary packages inside the environment such as gym, stable-baselines, pybullet, tensorflow.

OpenAI Gym is a toolkit for developing and comparing reinforcement learning algorithms. This is the gym open-source library, which gives you access to a standardized set of environments. GYM makes no assumptions about the structure of your agent, and is compatible with any numerical computation library, such as TensorFlow or Theano. Stable Baselines is a set of improved implementations of reinforcement learning algorithms based on OpenAI Baselines. OpenAI Baselines is a set of high-quality implementations of reinforcement learning algorithms. Using Baselines will allow us to focus on creating the environment and not worry about training the agent. Pybullet is an easy to use Python module for physics simulation, robotics and deep reinforcement learning. TensorFlow is an open source software library for high performance numerical computation.

5. DEEP Q-LEARNING ALGORITHM

Self balancing of our motorcycle robot was analysed using the Deep Q-learning algorithm[8]. The basic working step for Deep Q-Learning is that the initial state is fed into the neural network and it returns the Q-value of all possible actions as on output. It is basically an algorithm that learns on pairs of examples input and output data, detects some kind of patterns, and predicts the output based on an unseen input data.
In Q-Learning Algorithm[10], there is a function called Q Function, which is used to approximate the reward based on a state. We call it Q(s,a), where Q is a function which calculates the expected future value from state *s* and action *a*. Similarly in Deep Q Network algorithm, we use a neural network to approximate the reward based on the state. In order to shape an appropriate reward function for balance, we first determine what behavior in the bike model can help avoid a fall.

The training data used were: say T(X,Y) where X is the current velocity of the reaction wheel and Y is the change in velocity(i.e., one of the actions). The Q-value of all possible actions is generated as the output. For each action performed by the agent (the motorcycle), it would receive a reward : positive or negative reward. Further training and changing the incentives of the reward function of the motorcycle could train it to balance longer. Deep-QL is used when state space or action space are too large. By using neural networks, we can find other state-action pairs that are similar.

Figure 9 shows the motorcycle trained in a Pybullet simulation environment and the initial motorcycle model was able to balance in the environment similar to the way you see in the figure.

During the simulation process, the Miniconda command prompt shows an output eg : Figure 10

% time spent exploring - The time spent by the model in exploring new actions or the time spent on training the model.

Episodes - Each task is divided further into smaller modules called episodes.

Reward- The amount of reward achieved by previous action. The goal is to maximise the reward.

Step- Each time step of Simulation accepts an action from the agent and returns a tuple i.e. the time set for training the model.

Fig-9: Balanced MOTOBOT during simulation

% time spent exploring	2
episodes	6800
mean 100 episode reward	-1.5
steps	327139

% time spent exploring	2
episodes	6900
mean 100 episode reward	0.8
steps	336589

Fig- 10: Miniconda command prompt showing the output

CONCLUSION

In this study, we have discussed the existing self balancing vehicles and the advantages of our motorcycle model over these systems. We have successfully completed the simulation of our Initial self balancing Motorcycle model. Although at this stage our present work cannot be conclusive, the preliminary simulation results showed that the model was able to balance in the created environment with required packages. On giving further training and changing the parameters affecting the DQN function, we would be able to balance the motorcycle with the actual measurements or the final prototype. After this, we are also planning to implement the 3-D Motorcycle hardware model by transferring our balanced simulated model onto it using Raspberry Pi.

In a nutshell, there are several ways in order to design an efficient self-balancing motorcycle. The proposed system using reinforcement learning technique could be considered as energy efficient. The project demonstrates the remarkable use of self-balancing motorcycles for people whose concern is safety and people with certain disabilities. Two wheeled self balancing robots are an area of research that may well provide the future locomotion for everyday robots. The system could be more useful in future when there is high demand for electric vehicles because of the lack of fossil fuel.

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