Research Journal of Applied Sciences, Engineering and Technology 8(15): 1754-1761, 2014
DOI:10.19026/rjaset.8.1160
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: September 13, 2014 Accepted: October 11, 2014 Published: October 15, 2014

Research Article

Human Ensuing Self-balancing Automaton Based on Motion Sensor

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Abstract: Travel has become one among rudimentary necessities for every individual. Handling baggage plays an important role while travelling and for typical nomads it is cumbersome when heavy. With the proposed concept which will be dealt in this study, the baggage need not be pulled by us; it just follows us detecting our presence. Hence, the baggage is simply nothing but a robot. Prototype of motion sensor based human following robot that can balance itself in two wheels, thus behaving as a suitcase with intelligence and hence named Smart Suitcase. Concept of inverted pendulum helps in balancing. Regenerative power saving is established, when on its normal movement by the user wherein the saved power can be used for charging mobiles, laptops, torch lights etc. (low voltage applications). Passive infrared sensors fed with inbuilt intelligence in responding only to human presence helps this robot get even smarter.

Keywords: HCI, inverted pendulum, intelligent, passive infrared, regenerative power, travel

INTRODUCTION

This Smart Suitcase proposed can sense the human presence and can follow the sensed human at a range of 50-100 cm (adjustable) balancing it in two wheels behaving as a normal suitcase. Its algorithm is in such a way that it does not become sensitive to any objects or animals walking around giving impulse to sensors. Regenerative power saving is enabled so that when user rolls the automaton in normal mode, motors attached with wheels serves as generators and save power to batteries which later can be used for small charging units like torch lights, mobiles, laptops or the robot itself. When robot is left all of a sudden without any human supporters at any inclined angle, it gets back to its initial (vertical) Position robotically. This is the brief idea of Suitcase that can take travel to next generation.

Existing suitcases over robotic wheels can bring about a trendy change to whole world of travel. Brushless in-wheel dc motors will be used to carry the suitcase so that motors do not add to the complexity of size and of course weight too. Passive Infrared Sensor (PIR) is used for human motion detection. Specific sensor setup with ultrasonic (analog) and infrared (digital) sensors are designed for the robot to detect human ranging details and direction. Based on sensor inputs, actions are programmed for robots movement.

Combination of Accelerometer and gyro sensors is used for its self-balancing properties through concept similar to inverted pendulum. RF-id is used for tracking its owner.

On-board intelligence is the controller board placed to interact with real time sensors and govern the aim of the robot. Regenerative power flexibility is enabled during normal mode hence the motors also act as generators during its operation.

Ni-MH heavy density batteries act as power source for the entire system. Figure 1 clearly explains the system in brief. Microcontroller acts as central system interfacing all the subsystems. Sensors have a one-way passing signal (only from sensors to controller), whereas batteries and motors have a two-way signals for regenerative power.

The study is organized with a clear start on system configuration and then it navigates to how the prototype is sculptured. And next, the attention is paid on sensors and microcontrollers which are used in this innovation. Attention is then moved towards the driver circuit. Finally, a line of conclusion has been drawn with references also being cited.

MATERIALS AND METHODS

System configuration: The system consists of sensors network and few concepts mainly involved based on sensor inputs. The proposed system is shown in Fig. 1.

Sensors:

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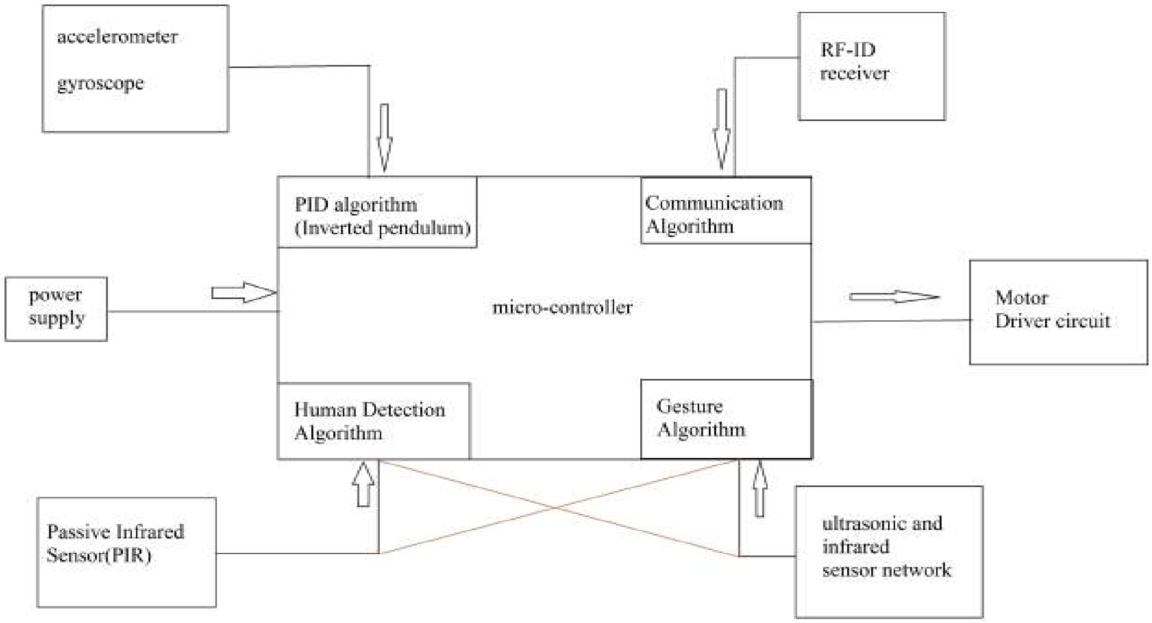

Fig. 1: Block diagram of the proposed system

- **Passive infrared sensor:** The sensor that detects humans based on their body temperature and motion. First, this sensor will detect any human motion nearby and filter out objects that are standstill. Second, this sensor will be more sensible to humans comparatively hence it can avoid any animal or object movements (Fradin, 2004).
- **Ultrasonic sensor:** The sensor is used to calculate the Distance Range between robot and the human user. This sensor is used to alert the user if the robot is following or not.
- **Infrared sensor:** The sensor is again used for distance calculation, but the sensor acts digitally for detecting the presence of human and to search for direction of human movement. This sensor is placed as network for better performance.
- **Accelerometer:** The sensor senses the acceleration of the robot when in motion and gives feedback for the concept of inverted pendulum.
- **Gyroscope:** The sensor detects the direction of acceleration for the robot to balance in the accurate direction.
- **Inverted pendulum:** With the help of accelerometer and gyroscope, the suitcase can be balanced on two wheels with the concept of Inverted pendulum. This has centre of mass above the pivot point, which is the balancing point. Once, the balance breaks, the system tries to regain balance by receiving excess torque from the feedback path. Hence, the Centre of mass is maintained. The inputs from both of the sensors are given to controller which is coded to behave as PID controller. Hence considering the position and speed of the suitcase, the feedback is given which will govern back the robot for its proper balancing.
- **RF-id:** This module is used to make robot understand who the user is. With its unique tag for every module it helps the suitcase follow its owner only.
- **Motors and battery:** There is wide range of motors available for the robot. Based on the torque requirement of the suitcase the motors are chosen. Brushless In-wheel motor is the state of the art technology which can be an option for this suitcase unless cost is not a considerable factor. This motor can be directly put in the wheel (the rotor is in contact with the wheel) unlike the conventional ones wherein only the shaft runs the next stage of rotating equipment. The hub motor has been preferred not only because it is advantageous for the operation (it pulls the wheel directly) but also, in physical structure and losses point of view. The normal brushless DC motor has a massive stator with poles for the windings. This results in enormous weight of the entire casing and also, eddy current losses and hysteresis losses in the stator winding become significant. As the amount of conductor material needed also becomes large, resistive losses predominate. The suitcase when operating in normal mode, i.e., when pulled by the user, the motor begins to work in the generating mode wherein, the mechanical energy used to drive the rotor is the human force. This generating mode of the motor generates DC voltage and is stored in a battery which could be used for charging mobile phones, laptops, torches etc. during travel. This is

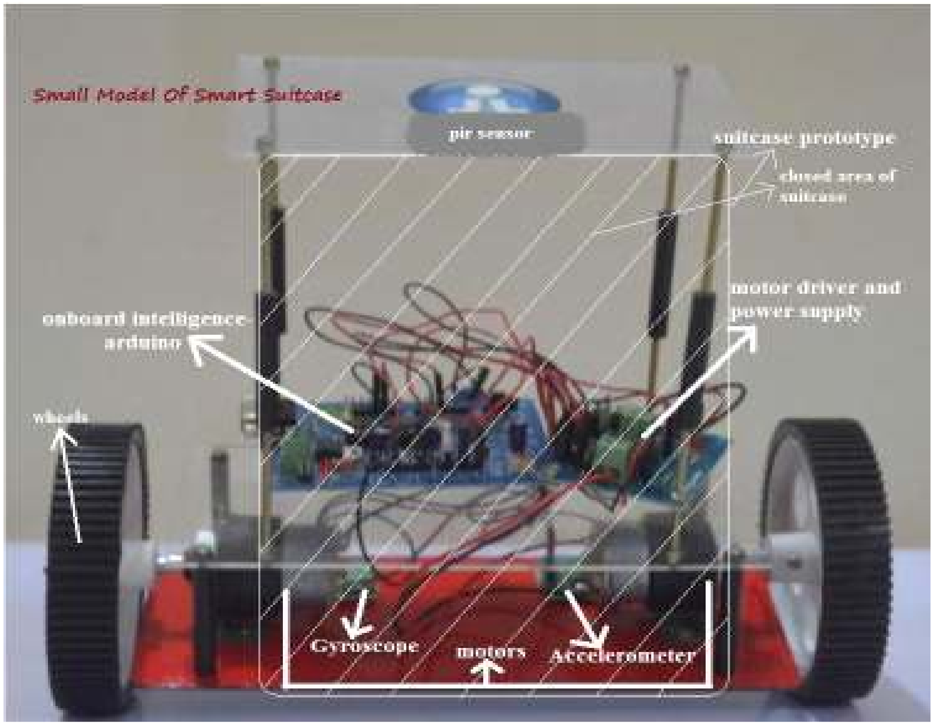

Fig. 2: Prototype of smart suitcase

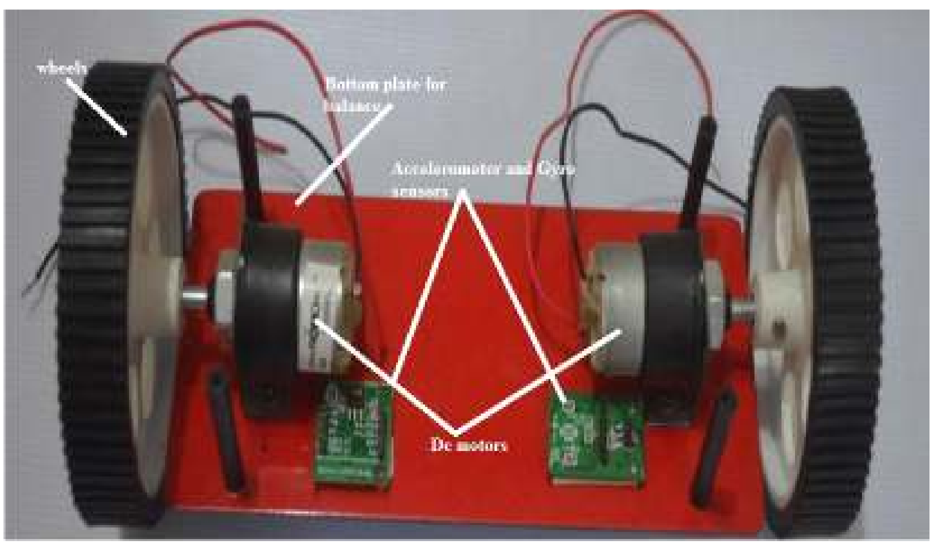

Fig. 3: Bottom plate with sensors for support

the regenerative action of the hub motor (brushless in-wheel motor). This regenerative action not only enhances the prospects of the system but also the energy is being used effective to make the motor work as a generator. Once, the external pull is removed, the generator comes back to the motoring mode. The battery rating will be in 1-3 Ah.

Prototype description: Model of the suitcase is created by a small two wheeled robot as given in Fig. 2. The sensors are placed on flat surface of suitcase for balancing its weight according to load as shown in Fig. 3.

The PIR sensor is placed on top so that it gets to detect the legs of any human as calibrated. The shaded region represents the closed area of the suitcase for loading. DC motors are placed on centre of the bottom plate such that weight distribution is made equal. The Fig. 4 shows the prototype model.

Sensor network: To detect the motion of the human and to sense the gesture from the user, a particular

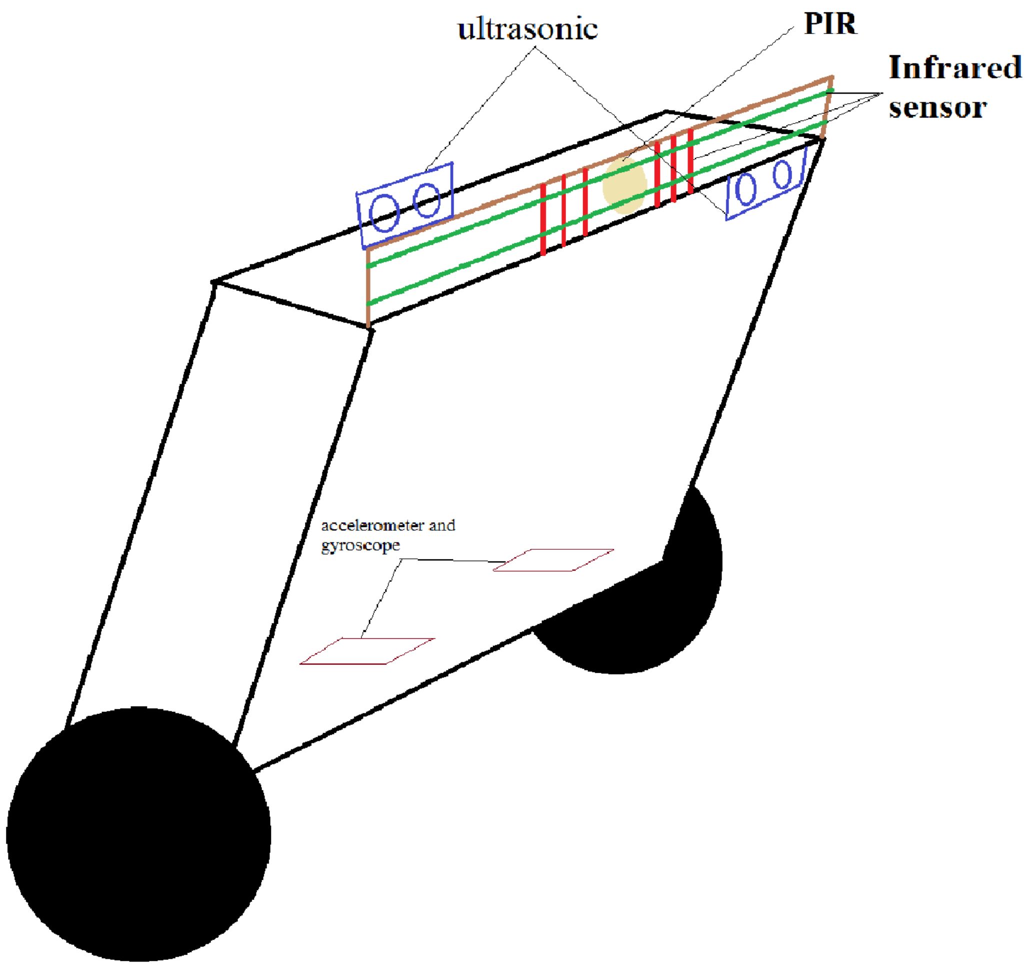

Fig. 4: Prototype of real-time smart suitcase

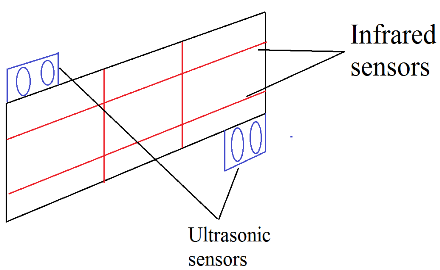

Fig. 5: Sensor network for gesture recognition.

sensor network is designed using ultrasonic, Infrared and PIR sensors. The sensor setup is as shown in the Fig. 5. In the Fig. 5, the red line represents the infrared sensor strips and blue box denotes the ultrasonic sensors. The PIR sensor will be placed in middle of the sensor network for human motion detection.

The infrared sensors are placed in horizontal and vertical way to detect the motion of human in right or left side with respect to Centre and ultrasonic sensors are placed to detect the range of human from that of suitcase. Passive Infrared Sensors are destined to sense the motion of human and so helps to detect human presence for the robot to function. Figure 5 is helpful to understand the above conveyed concept.

Microcontroller and interfacing: The inevitability of microcontroller usage in this proposal has to be discussed. Embedded systems normally carry microcontroller inside it for performing the desired tasks (our system is also an embedded system). The choice of controller is the most important aspect to be considered in the project. Since there are numerous microcontrollers available in the market, it is really a pain and more than that it is a challenge to select the right one for the embedded system. We also as authors faced the same problem and after going through lot of data sheets and analysis have selected mbed NXP LPC1768. It is a full-fledged embedded board which is readily available in the market. Few of the features are highly glamorous and definitely notable. ARM Cortex-M3 is the heart of the kit and it is one of the most frequently used one in the embedded market. USB drag and drop programming is another effective and efficient to be applauded with this kit. API driven development environment will give the programmer a comfortable feel with the kit. Then finally there is one more feature which is state of art of the kit. It has online compiler which will make the user free from installing lot of software in the machine. One just has to login and upload the code, use the online compiler, get the code compiled, then finally execution has to be carried out. In short, it will be very friendly, inexpensive, highly efficient platform for the programmers and innovators (Kothari *et al*., 2012a). Figure 6 is revealing the pin layout of the mbed microcontroller.

- **Convenient form-factor:** 40-pin DIP, 0.1-inch pitch
- Drag-and-drop programming, with the board represented as a USB drive
- **Best-in-class Cortex-M3 hardware:**
  - Ethernet, USB OTG
  - SPI, I2C, UART, CAN
  - GPIO, PWM, ADC, DAC
  - 100 MHz ARM with 64 kB of SRAM, 512 kB of Flash
- **Easy-to-use online tools:**
  - Web-based C/C++ programming environment
  - Uses the ARM Rea View compile engine
  - API-driven development using libraries with intuitive interfaces
  - Comprehensive help and online community (Kothari *et al*., 2012b).

The input from the sensors will be fed in through the Analog input points available in the chip. And the output can be in the digital form and can be taken in the PWM (Pulse Width Modulation) format from the output pins. The digital output can be then used to drive the driver unit of the motor.

Communication technique: The robot has to communicate with human in some way, so as to maintain the constant distance and keep track of the particular human. This is done through a carefully designed algorithm. The physical module used for communication is the RF-ID module. The user carries the transmitter chip and receiver is with the robot. so the robot tries to keep up its range with the transmitter chip. The constant distance is maintained through sensor network placed on suitcase. The below mentioned figure explains how the suitcase will track the human with the given range from RF-transmitter. The range of RFID varies with respect to human motion and so the distance between the robot and the human. So to maintain the constant distance and to be within the range of RFID is the aim of the robot. Figure 7 stands in support for how robots track the path of human.

The sensor network and RFID's range varies for the perfect functioning of human assistance. The algorithm will be designed with much sensitivity such that the line of sight for the sensor network is proper according to movement of human since it is not always necessary that the human must walk in straight line. Also the speed of the motor is varied depending on the distance and speed of the human. Figure 8 is a simple and elegant representation of the scenario.

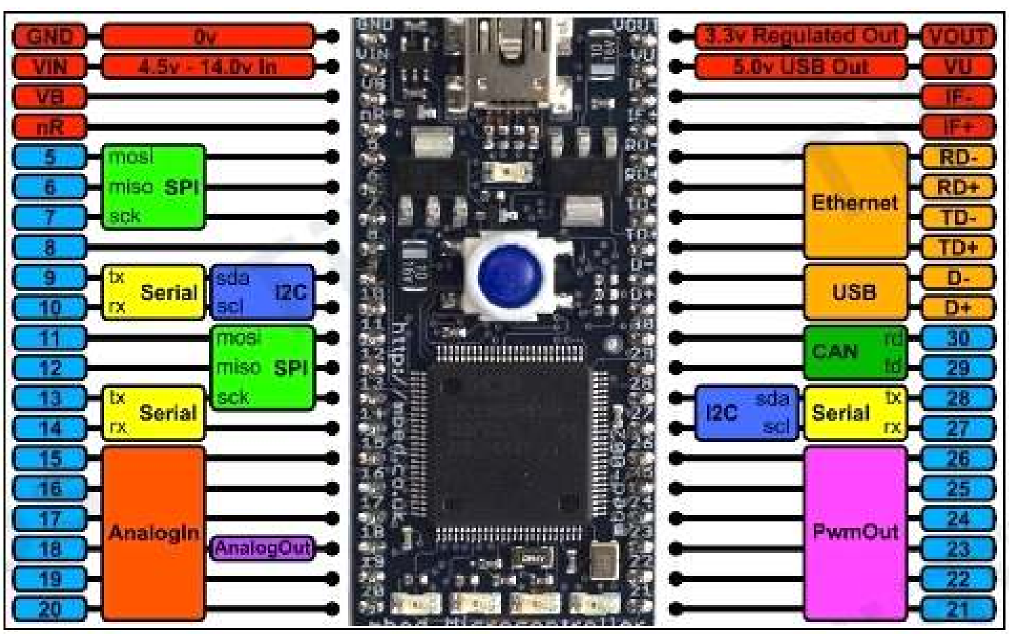

Fig. 6: mbed lpc1768 microcontroller

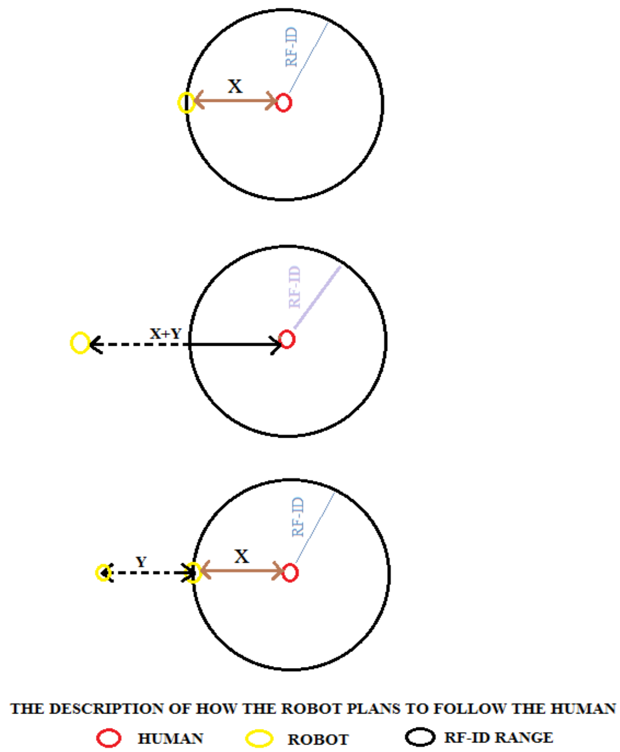

Fig. 7: Description of how robot tracks the path of human

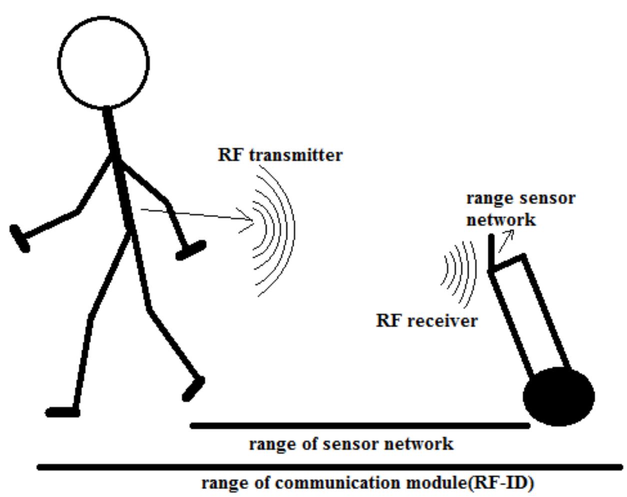

Fig. 8: How communication happens for ensuing

Concept of inverted pendulum: The concept of inverted pendulum involves the balancing of a basement at the pivot point. If at all the balance breaks, the basement gets balanced again by receiving additional torque from the feedback path. The accelerometer output, speed and gyroscope output, angle are the inputs to the PID controller. Figure 9 is presented for understanding the concept of inverted pendulum. The P in PID stands for proportional, which changes torque based on present information, which is directly based on angle error:

$$\text{Pterm} = \text{angle error} * \text{Pgain} \quad (1)$$

The I in PID stands for integral, which changes torque based on past information and what has occurred:

$$\text{Iterm} = (\text{Iterm} + (\text{angle error} * \text{Igain}))*0.9999 \quad (2)$$

The D in PID stands for derivative, which changes torque based on future trajectory:

$$\text{Dterm} = (\text{angle error} - \text{old angle error}) * \text{Dgain} \quad (3)$$

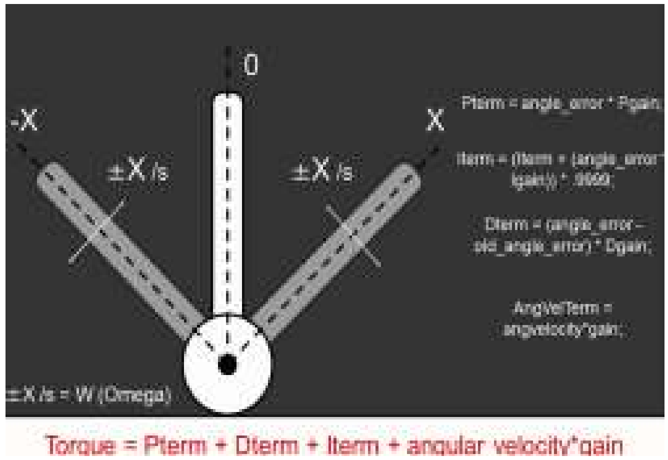

Fig. 9: PID controlled inverted pendulum

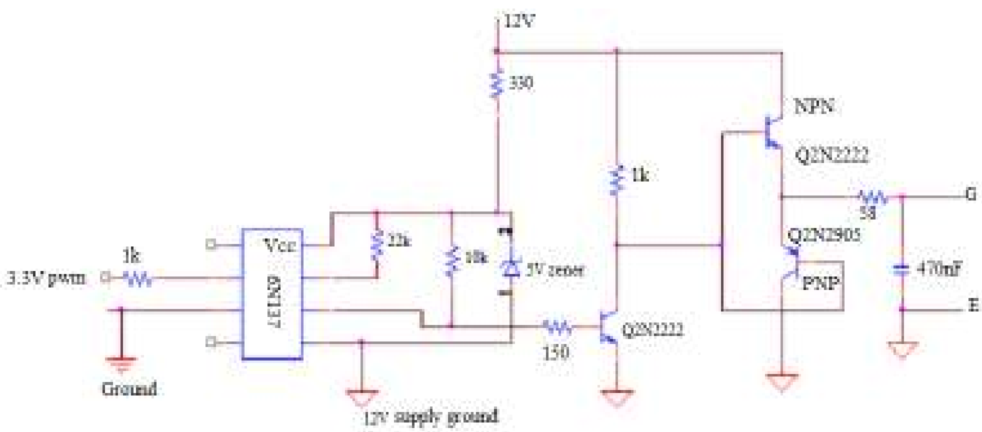

Fig. 10: Motor driver circuit

The PID controller changes or rather controls thee feedback torque which is necessary to maintain or balance the basement of the robot.
The transfer function is as follows:

$$G_{c(s)} = \frac{U_{(S)}}{E_{(s)}} = Kp + \frac{K_i}{s} + K_d s$$

$$= K_p\left(1 + \frac{1}{T_i s} + T_d s\right)$$

where,

$$T_i = \frac{K_p}{K_i}$$

and

$$T_d = \frac{K_d}{K_p}$$

$$= K_p\left(\frac{T_i T_d s^2 + T_i s + 1}{T_i s}\right)$$

Depending on the speed, angle and motor design constraints, the co-efficient of the transfer function changes.

Motor driver circuit: The driver circuit (Fig. 10) is used to drive a power electronic switch connected to the motor. The PID algorithm provides a PWM (Pulse Width Modulated) output that in turn, drives the circuit. This switching operation is performed by using the driver circuit. The IC used here is 6N137, high-speed optocoupler IC. This is designed for its usage in high-speed digital interfacing applications which requires high voltage isolation between the input and output.

RESULTS AND DISCUSSION

This smart suitcase when into implementation has innumerable application.

Household: For the household activities, such as carrying the luggages from one end to other and assisting with cleaning stuffs and serving foods.

Fig. 11: The concept of smart suitcase

Shopping: With trolleys being placed in all shopping malls, the idea of smart suitcase module can make the trolley follow the customer till he is done with the shopping. This could decrease the stress on customer and increase the sales due to attractiveness.

Travel: As stated, the primary purpose of the idea was to help human with his load during travel in any mode of transportation. Say road, air or water. It helps the human with his load at railway stations, airports and bus stops or even in picnic spots.

Military: Inspite of being dutiful, most of the times military persons are required to carry heavy weapons even during off-war period, so this concept will help them to relax during wanted times.

Differently abled humans: For people who can't walk or got hands cut or even when not well with respect to health such as sprain or joint break, this idea of smart suitcase will help them to maximum possible with their luggage during travel.

Industry: In industry's, for pick and place operations the concept of smart suitcase can be extended for more loads to assist the humans with operations to be carried without consuming much space, power and time. Unlike in case of traditional conveyer system.

Smart suitcase once into action can help humans in their routine life. The luggage will never be a burden during travel to humans. Though initial stages might be confusing but on day-to-day usage this will be much more comfortable (Fig. 11).

Worries about stealth and distractions or following up a different owner in rugged situations are general with this idea but state of the art algorithm with a bit of calibration can take up this smart suitcase as consumer electronics. Disabled and elderly people can make use of the concept to maximum extent as physical load is a great burden to them.

CONCLUSION

Smarter solutions to routine works arise from technology every now and then. Smart suitcase will be designed such a way it reduces human effort over luggage to nil. Like a pet getting to detect its owner and follow, smart suitcase will do it in mere future and basic concept of regenerative power is much useful for its power saving nature.

Image processing is the main concept that is used currently for human following. Once the idea is implemented, bringing in a camera can substitute few sensors and make it much more feasible. Still our nature is analogous hence to follow that; sensors will be of great help than camera.

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