KUGEL BALANCE: BALLBOTS - THE FUTURE OF PERSONAL TRANSPORT?

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Abstract — There has been a constant desire for easy travel to simplify life with numerous attempts made to achieve the same. Present day transport devices are restricted to motion in a single direction and various steering constraints. Kugel balance (ball balance) is a personal transporter which aims to solve this problem by using the concepts of omnidirectionality and self-balancing. It achieves the above two properties by utilizing a ball instead of conventional wheels for traversing in a plane. This paper is an exploratory step towards achieving this in a simple, functional and cost effective manner. Inspired from a class of robots called Ballbots, a single point of contact is achieved between ball and ground. A person riding the Kugel balance is capable of traversing in any direction at a given instant by gently leaning in the desired direction of travel while seated on the device. A lot of research has been carried out with respect to omnidirectional systems particularly in the field of mobile robotics for improved human-robot interaction. The structure, mechanism, initial observations and results from the Kugel Balance along with learning from a small scale prototype are described in this paper.

Keywords— Ballbot, omnidirectional, IMU

I. INTRODUCTION

“Omni” in Latin means all or every. Therefore the term omnidirectional is in contrast with “unidirectional” or “bi- directional” i.e. omnidirectional bodies can practically move in any direction on a 2D plane at any given instant. The “ball mouse” for example is an omnidirectional device. The motion of the mouse causes the ball inside to roll, resulting in rotation of 2 counter-wheels/rollers, one for each planar axis. The information received at the counters would then be translated to the motion of the cursor on the screen using pre-written algorithms.

Imagine the reverse phenomenon, a torque applied to the ball by the counter wheels with the help of motors and the ball movement being controlled by the computer. This would result in an omnidirectional device. This is the “Inverse Mouse Ball Drive” concept which was employed by ballbot researchers at Carnegie Melon University (CMU) [1]. This ballbot uses two orthogonal rollers to drive the ball with support from two idler rollers. Rollers are driven by servomotors with the help of a belt drive mechanism.

In contrast, the Tohoku Gakuin University (TGU) ballbot [2] used a more complex mechanism to drive the ball. Three stepper motors oriented at 120 degrees with omniwheels providing the final drive to the ball. The ability of the TGU ballbot to yaw and also provide a direct drive mechanism could be considered as additional advantages. The University of Adelaide Ballbot [3] was built in order to accommodate balls of different sizes and also used omniwheels for driving the ball directly. The drive mechanism supports were oriented at 45 degrees and resulted in a simple and ergonomic design.

Rezero [4] has its drive mechanism oriented in a similar way as that of the TGU Ballbot [2]. Apart from stability, Rezero also focused on agility. Rezero was equipped with sophisticated vibration isolation dampers and also laser and proximity sensors which enabled human interactions such as following a person by maintaining a constant gap. These sophistications in our opinion resulted in a very smooth and elegant ballbot. Based on the study of these various mechanisms, a small scale prototype was built to study the behaviour of such a system, details of which are mentioned in the next section.

II. THE PROTOTYPE

Fig. 1 shows a small scale prototype which draws its design from the “inverse mouse ball” concept. Figure shows the prototype in its inverted position.

Perforated steel plates and simple DC motors were used for its construction. Basic ATMEGA processor and L293 motor controllers/drivers were used for controlling and powering the motors. Accelerometers and gyroscopes were used as tilt sensors. Manual tuning of potentiometers was required to set the “zero point” for the system. It can be observed from the figure that this prototype drive mechanism consisted of two active drivers in the form of wheels and two support ball transfers.

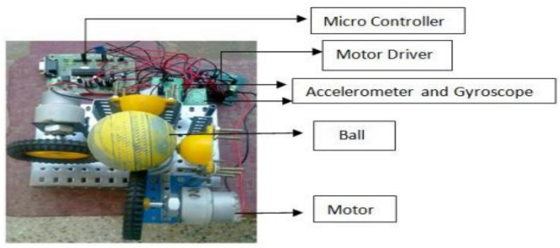

Fig 1: The prototype

On performing basic checks (by tilting the gyroscope and accelerometer) for the drive and omni directionality, it was observed that the ball kept ejecting out of its place due to the unbalanced tractive forces. Solution to this problem was to make use of 4 drive motors and replace the passive drive points by the additional two motors. With equal drive on opposite sides we have one side pushing upward and one side pulling downward. The forces are nullified and there is no net force to eject the ball out.

III. SYSTEM DESCRIPTION

Fig. 2 shows the various views of the basic structure of the Kugel Balance modeled in CATIA V5 R19. Based on the results observed from the prototype it was decided to go with the 4 omni wheels driven individually by motors as seen in the bottom view. Torque demand arising due to heavy loads is fulfilled by using the 4 motors to drive the ball. Ball transfers were used to transfer the load of the system to the ball and finally to the ground. Various combinations of ball transfer orientations were attempted. A hemispherical orientation with 5 ball transfers and a triangular 3 ball transfer orientation were also looked into. However, for the sake of simplicity the four ball transfer orientation was used.

Cost being a design parameter, the material used for the bottom plate was mild steel. The welded hash pattern provided structural reinforcement and prevented flexing of the plate during welding of accessory components and also under heavy payloads. A lightweight aluminium frame formed the vertical build of the system. Space inside the frame housed the circuits and powering devices with the battery pack on top.

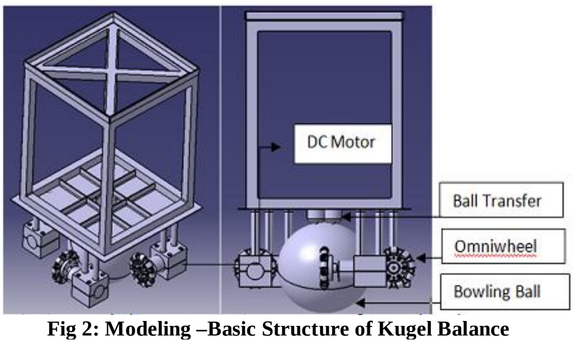

Fig 2: Modeling –Basic Structure of Kugel Balance

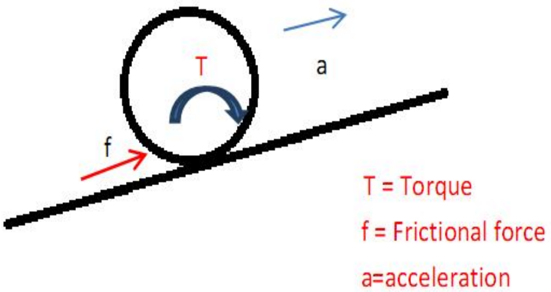

Fig. 3 Inclined plane scenario

Since the system is placed on a ball, its natural tendency is to tip over. An on-board Inertial Measurement Unit (which is nothing but a combination of accelerometer and gyroscope) detects the tilt and feeds this as an input to the microcontroller which takes corrective measures to re-stabilize the system to its erect position by driving the necessary motors. The purpose of this correction is to bring the ball underneath the center of gravity of the system. This is analogous to trying to balance a stick on one's finger. A person riding the Kugel Balance just has to lean forward in order to shift the center of gravity of the system and thus resulting in corrective forward motion to bring the system back to a balanced state. By merely exploiting the tendency of this system to perpetually re-stabilize itself, we only need to de-stabilize it to make it move.

A simple bowling ball which provided fairly good traction was chosen over a basketball in order to overcome local deformations at the point of application of load.

The ARDU IMU and ATmega328 based ARDUINO UNO microcontroller was used for tilt sensing and controlling respectively. The open source ARDUINO platform was used for coding. Table I shows the specifications of the Kugel Balance.

Fig. 3 indicates that the torque calculation scenario for the motors was based on a state in which a robot is not just stationary on an incline, but also accelerating up the incline.

Thus an appropriate torque value was obtained by applying the concepts of Newtonian mechanics.

TABLE I. KUGEL BALANCE SPECIFICATION

Total Height	0.75 m
Total Weight	18 kg
Ball Diameter	0.218 m
Ball Weight	2.72 kg
Ball Transfer Capacity	50 kg (inverted position)
IMU	ARDUIMU
Controller	ARDUINO UNO
Omniwheel diameter	0.1016 m
Battery	12 V Lead Acid

Proportional Integral Derivative (PID) control system was used as the control loop mechanism. The PID controller consists of three main terms: the proportional term, the integral term and the derivative term. The constants kp, ki and kd associated with these terms had to be manipulated to obtain the desired response from the device by virtue of output coming from the control loops which run perpetually in the microcontroller program. The manual tuning method was adopted to observe the system response.

Table II illustrates the different permutations used and the response of the system to the variation in the different parameters. During testing on a household tiled floor, it was observed that the system was able to balance fairly well. However a failsafe roof suspended snap chord support was always used in order to prevent any major injuries or damage in the event of a system restart or error.

DISCUSSION

The above results indicate that this system is still in a very elementary stage and much development and refinement is necessary. Improved and efficient techniques for optimizing the tuning of control loop parameters are being looked into. Also in order to qualify the system as a transporter, a certain degree of safety needs to be incorporated into the system. Some safety measures could include the introduction of emergency brake system and also impact protection in case of fall. These could be incorporated along with the improvement of aesthetics and ergonomics of the system. However, such a concept when further developed to the level of real world transporters could potentially overcome the various problems related to space constraints and steering geometries. Applications especially in controlled environments include material movement in massive shop floors, aides in hospitals, schools, offices, super-markets, airports, to name a few and also a transporter on similar lines as the Segway [5] in applicable areas.

TABLE II.

SYSTEM RESPONSE TO VARIATION IN LOOP TUNING PARAMETERS

Kp	Ki	Kd	COMMENTS
1	2	4	Poor Balancing with strict assistance required
1	1	4	Tilt response smoothens out due to reduction of overshoot parameter
1	0	0	Smooth but very slow response
2	0	0	Sudden response after some tilt
3	1	4	Faint appearance of independent balance
3	2	4	Good response with violent vibration
3	2	9	Fair response with smoothened vibration
3	2	15	Very sensitive to noise in the system and hence unstable
3	3	9	Sudden response on tilt with hint of over correction
3	5	9	Sudden response with high amount of over correction
2	1	9	Relative improvement in balance but with sudden correction
0.5	0.5	9	Fairly Balancing with a lot of vibration but with no sudden correction
0.5	1	9	Balanced with faster response with noteworthy vibration levels

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