

COMPACT PERSONAL TRANSPORTER

TECHNICAL FIELD

This invention pertains to the control of a compact personal transporter for enhanced dynamic stability and more particularly to devices and methods for using the centre of gravity of the user for providing user input for directional or acceleration control. More specifically, it applies to a personal transporter that has 3 or more ground contact elements for static stability but by virtue of its compactness and having a small footprint, raises the risk of dynamic instability.

BACKGROUND OF THE INVENTION

A wide range of personal transporters designs are known, both the dynamically stabilised having one or 2 wheels, and the statically stable with 3 or more ground contact elements. Amongst the statically stable, designs are typically large with a wheel base length typically over 700mm and a width of 500mm to ensure sufficient stability to account for the forward momentum and lateral forces when turning. These vehicles are controlled by handle bar steering with a throttle, such as a twist throttle or similar and therefore do not account for the positioning of the user of the vehicle. The design of such vehicles therefore preclude compactness and compromises portability, leading to vehicles that are heavy and of a size compromising easy hand portability.

SUMMARY OF INVENTION

In one embodiment, there is provided a vehicle for carrying a payload including a user. The vehicle of this embodiment includes:

- a. a stable platform which supports the user even when unpowered;
- b. a ground-contacting module to which the platform is mounted, which propels the user in desired motion over an underlying surface; consisting of 3 or more ground contact elements; with two independently powered wheels that form the primary drive and a third or fourth wheel, that is free swivelling, located either to the fore or aft of the 2 primary drive wheels;
- c. force sensing elements to allow the determination of the orientation and locus of the centre of gravity of the user;
- d. restraints as needed at the feet to secure the user as weight is being shifted to control the motion of the vehicle;
- e. a motorized drive arrangement, coupled to the ground contacting module; the drive arrangement, ground-contacting elements and payload constituting a system; the motorized drive arrangement causing, when powered, to achieve kinaesthetic control defined as the control of the vehicle to a user input, based on a shift of the user's centre of gravity, automatically maintaining the centre of gravity so that it passes through within a limited prescribed region around a predetermined point on the platform of the system;
- f. a unit comprising a platform, ground contacting module, the drive arrangement and ground contacting elements, handles for hand portability; utilizing low weight materials and components; having a compact form factor to maximise portability.

In a related embodiment, the ground contacting elements a ground-contacting module to which the platform is mounted, which propels the user in desired motion over an underlying surface; consisting of 3 or more ground contact elements; with two powered wheels that form the primary

drive and a third or fourth wheel, that can swivel using servo control, located either to the fore or aft of the 2 primary drive wheels.

In second related embodiment, the ground-contacting module to which the platform is mounted, which propels the user in desired motion over an underlying surface; consisting of 4 ground contact elements; with 4 wheels on fixed axles, set closely together so as to limit resistant to turning; the left and right being independently controlled.

In third related embodiment, the ground-contacting module to which the platform is mounted; consisting of 4 ground contact elements; each wheel being independently driven and steered, which propels the user in a desired motion over an underlying surface; having the characteristic of sideways motion in addition to the forward and yaw motions.

In fourth related embodiment, the ground-contacting module to which the platform is mounted; consisting of 4 ground contact elements using Mecanum wheels; each wheel being independently driven, which propels the user in desired motion over an underlying surface; having the characteristic of sideways motion in addition to the forward and yaw motions.

In accordance with these embodiments, to maintain the system centre of gravity around an initial locus, a controller is provided to compute, from the 4 force sensing elements in the platform, the locus of the centre of gravity of the user on the platform, including corrections to account for shifts in the centre of gravity due to forward or lateral accelerations caused by the vehicle, as an input specification by the user for the desired motion or orientation for the transporter. It computes the 3 basic modes of orientation of a user's body position and weight. Beginning with a user's neutral stance, the body may :

- a. be shifted forward or backwards;
- b. be shifted sideways to the left or right;
- c. be twisted clockwise or anti-clockwise;

The first mode, the forward or backwards motion of the body moves the locus of the centre of gravity of the user forward or backwards from the original position. The controller corrects this by generating an appropriate demand signal to the primary drive system to cause the acceleration or deceleration of the personal transporter thereby shifting the locus of the centre of gravity back towards the initial position. By setting appropriate gain values, the locus of the centre of gravity is controlled to remain within a safe boundary defined based on the wheel base of the transporter. In so doing, the transporter is kept stable.

The second mode, may be used in 2 ways, depending on the drive system of the personal transporter. In the first embodiment where in addition to the forward/backwards motion it has only yaw control, such as seen vehicles with fixed wheel and steered wheel vehicles, the second mode is used to control the yaw of the vehicle. In the second embodiment where the vehicle is provided with independent wheel control, the second mode is used for side-slip motion or a combination of sideways and yaw with at some controlled ratio.

The third mode, is used for turning the personal transporter, controlling the yaw rate desired.

In the case of embodiments where sideways motion is not allowed or desirable, the preferred control is to combine the second mode and third mode into a single mode controlling the yaw rate of the vehicle.

BRIEF DESCRIPTION OF DRAWINGS

The invention will be more readily understood by reference to the following description, taken with the accompanying drawings, in which:

FIGURE 1 is a perspective view of a lightweight and small personal transporter, which has at least 3 ground contact elements on a small footprint which can unstable when in motion, but in accordance with the present invention is able to maintain the centre of gravity of the rider for stability;

FIGURE 2 shows a lightweight and small personal transporter in accordance with the present invention to maintain motion stability, which has 4 ground contact elements on fixed axles to ensure static stability but with a short wheel base for reduced yaw resistance;

FIGURE 3 shows the lower portion of the platform with the force sensing plate separated, indicating the location of the 4 load sensing elements, indicated as C1, C2, C3 and C4;

FIGURE 4 shows a foot restraint to assist the user to lean backwards and shift the user's centre of gravity towards the rear of the vehicle;

FIGURE 5A shows a leg back rest to assist the user to lean backwards and shift the user's centre of gravity towards the rear of the vehicle;

FIGURE 5B shows a leg back rest stowed and used as a carry handle;

FIGURE 6A is a schematic showing the initial position or a user in a natural standing position;

FIGURE 6B is a schematic showing the user leaning forward to accelerate the vehicle;

FIGURE 6C is a schematic showing the user shifting to the left;

FIGURE 6D is a schematic showing the user twisting counterclockwise;

FIGURE 7 is a schematic for the close loop control scheme;

FIGURE 8 is a schematic indicating the forces present when the transporter is accelerating.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

In accordance to the various embodiments of the present invention, kinaesthetic control is achieved by having a rectangular platform supported by 4 force sensors placed towards the 4 corners as shown in figure (3). Sensor C1 is placed on the fore left, C2 on the fore right, C3 on the aft left and C4 on the aft right. The platform supports the user whose weight is therefore distributed to the 4 force sensors. This arrangement allows the locus of the centre of gravity of the user, starting from the initial rest position as shown schematically in figure 6A, to be computed by the controller. As the user shifts according to the 2 modes shown in figure 6B and 6C, the locus of the centre of gravity is recomputed. In the case of the twist of the body, resulting in the rotation of the orientation of the centre of gravity is also determined from the 4 force sensing elements.

With the 4 load sensing elements, the user's total weight (T_w) measured while the transporter is stationary is:

$$T_w = C1 + C2 + C3 + C4 \quad (1)$$

The centre of gravity locus of the user is computed, with respect to the reference plane of the transporter with its origin at the centre of the platform based on the 4 force sensors, using the

moment balance analysis as applied to each combination pair of the 4 force sensing elements to give 4 equations :

$$D1 = (C1 - C3) / (C1 + C3) \quad (2)$$

$$D2 = (C2 - C4) / (C2 + C4) \quad (3)$$

$$D3 = (C1 - C2) / (C1 + C2) \quad (4)$$

$$D4 = (C3 - C4) / (C3 + C4) \quad (5)$$

This is initially performed when the user stands on the platform, just before he initiates motion. Doing this provides the user's Total Weight (T_w) and the initial values of $D1_0$, $D2_0$, $D3_0$ and $D4_0$. From these initial values, 2 further parameters are also computed :

$$Y_0 = (D1_0 + D2_0) \quad (6)$$

$$X_0 = (D3_0 + D4_0) \quad (7)$$

To obtain the 3 parameters reflecting the kinaesthetic movement of the user as illustrated in Figure 6 (A)-(D),

$$\text{Forward shift, } F = (D1 + D2 - Y_0)/2 \quad (8)$$

$$\text{Side shift, } S = (D3 + D4 - X_0)/2 \quad (9)$$

$$\text{Twist, } T = (D1 - D2 + D3 - D4)/4 \quad (10)$$

Control of Vehicle

Control of the vehicle is effected using a close loop control scheme as shown in figure (7) where specific control gains K_A , K_V , K_L , K_R may refer to proportional and integral gain parameters. Considering first the forward shift input and the control of the acceleration of the vehicle, the acceleration of the transporter creates a reverse shift in the centre of gravity locus towards the rear of the vehicle, shown schematically in figure(). Therefore, unless added back, the user input signal is diminished. F , the acceleration force can be computed from total weight, T_w , multiplied with the actual vehicle acceleration, R , as measured directly from the rotation of the powered wheels of the transporter. Therefore, the forward acceleration command signal to the close loop motor controller illustrated in figure (8) is corrected by applying an appropriate gain parameter, G_A , so that

$$A = (D1 + D2 - Y_0)/2 + T_w R G_A \quad (12)$$

The gain parameter G_A is adjusted so that the command signal A corrects for the reverse shift in centre of gravity locus. Applied in control, when the command acceleration, A , is achieved, the term $(D1 + D2 - Y_0)/2$ will diminish towards zero, that is, the locus of the centre of gravity is returned to the initial position.

Following the same analysis, side shift, S , can be computed using the acceleration from the side motion drive motor, P , and applying an appropriate gain parameter, G_S , in the equation :

$$S = (D3 + D4 - X_0)/2 + T_w P G_S \quad (13)$$

A similar correction to the yaw rate, Y , can be applied. Using the speed of the left and right drive wheels, $V1$ and $V2$, the centrifugal force, F_c , can be computed as

$$F_c = T_w(V1+V2)(V2-V1)/(2d) \quad (14)$$

Where d is the distance between the left and right wheels. F_c may then be applied directly to give the yaw command signal Y , as appropriate with a gain parameter G_T so that

$$Y = T + F_c G_T \quad (15)$$

OR

$$Y = S + T + F_c G_T \quad (16)$$

It is noted that the gain parameters, G_A , G_S and G_T , are affected by the height of the rider and may be adjusted by user for desired comfort.

Inertial noise handling

Inertial noise due to travelling over rough ground, can be corrected for by one or both of the following methods : Total Weight error band method; Load cell acceleration correction.

For the Total Weight error band method, the error signal, E , can be defined as the instantaneous total weight measured, W , compared to the initial total weight, TW .

$$E = (W - TW)/TW, \quad (17)$$

Two parameters may be affected by error, E .

- (1) Deadband range, $R = C (1 + E G_d)$, where C is the minimum deadband range and G_d a gain parameter.
- (2) Noise Parameter, $N = E \times G_n$, where G_n is a gain parameter.

For Load cell acceleration correction, each of the 4 load sensors can be provided with an accelerometer placed co-axially with it, or as close as physically possible. The accelerometer may be single axis or multi-axis. With multi-axis accelerometer, computation is made to resolve to an acceleration vector acting on the load sensor. While a single axis (vertical) accelerometer signal can be used directly. From the vector signal, A , a corrected load signal can be computed by :

$$\text{Corrected load} = C_x - AG, \quad (18)$$

where C_x is the reading from load sensor $C1$ to $C4$, and G is a gain parameter.

In a simpler embodiment, 1 accelerometer to measure the overall acceleration vector and the correction is applied to the total weight W and so improve the total weight error band.

WHAT IS CLAIMED

1. A method of controlling a side shift (S) of a compact personal transporter having four load sensors (C1, C2, C3, C4), the method comprising:
 - 5 – receiving initial weight values ($D1_0$, $D1_0$, $D3_0$, $D4_0$) of a user from the force sensing elements (C1, C2, C3, C4);
 - receiving actual weight values (D1, D2, D3, D4) of the user from the corresponding force sensing elements (C1, C2, C3, C4);
 - calculating a twist force (T_w) according to the actual weight values (D1, D2, D3, D4) according to equation $T_w=(D1-D2+D3-D4)/4$;
 - 10 – receiving an acceleration value (P) from a side drive motor;
 - receiving a gain parameter of the side shift (G_s); and
 - calculating the side shift according to equation $S=(D3+D4-D3_0-D4_0)/2 + T_w P G_s$.
- 15 2. A method of controlling a yaw rate (Y) of a compact personal transporter having four force sensing elements (C1, C2, C3, C4), the method comprising:
 - receiving actual weight values (D1, D2, D3, D4) of a user from the force sensing elements (C1, C2, C3, C4);
 - 20 – calculating a twist force (T_w) according to the actual weight values (D1, D2, D3, D4) by following equation $T_w=(D1-D2+D3-D4)/4$;
 - receiving velocity values (V1, V2, V3, V4) of four wheels and a distance (d) between a left and right wheels of the compact personal transporter;
 - calculating a centrifugal force F_c according to equation $F_c=T_w(V1+V2)(V1-V2)/(2d)$;
 - 25 – receiving a gain value (G_T) of the twist force (T_w);
 - computing the yaw rate (Y) according to equation $Y=T + F_c G_T$.
- 30 3. The method of Claim 2 further comprising:
adding the side shift (S) according to Claim 1.

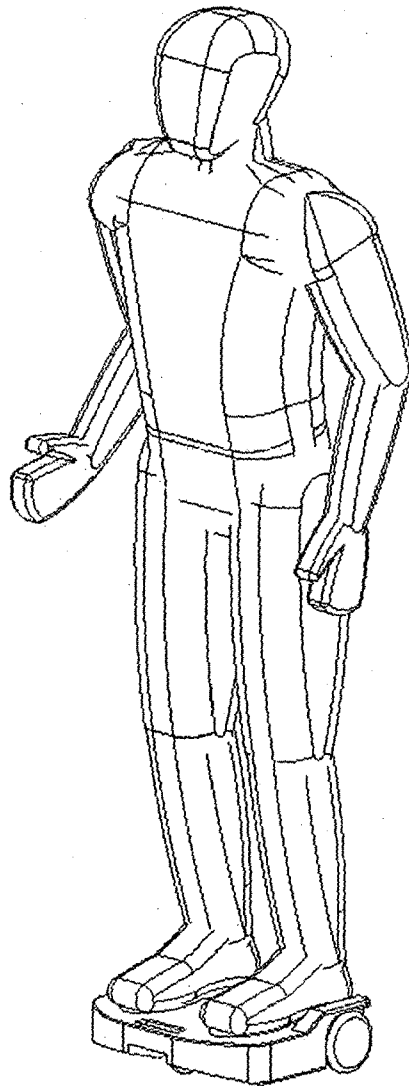


Figure 1

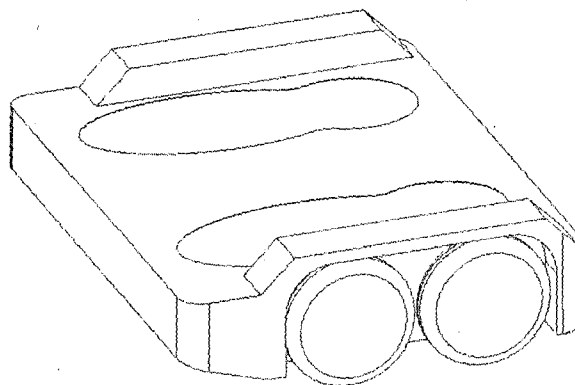


Figure 2

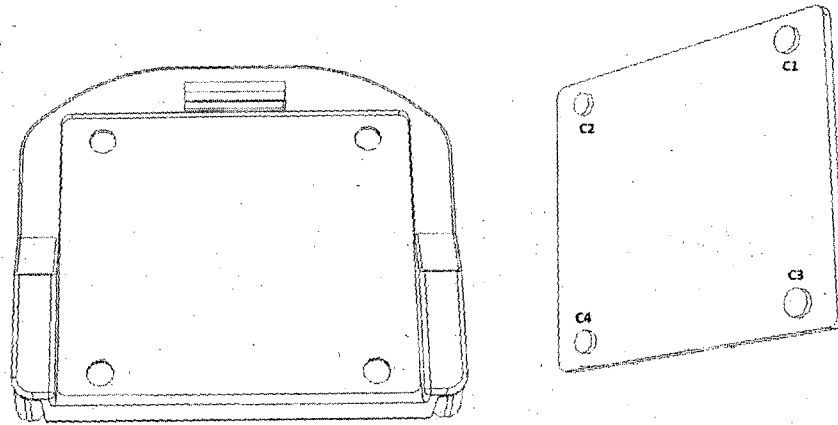


Figure 3

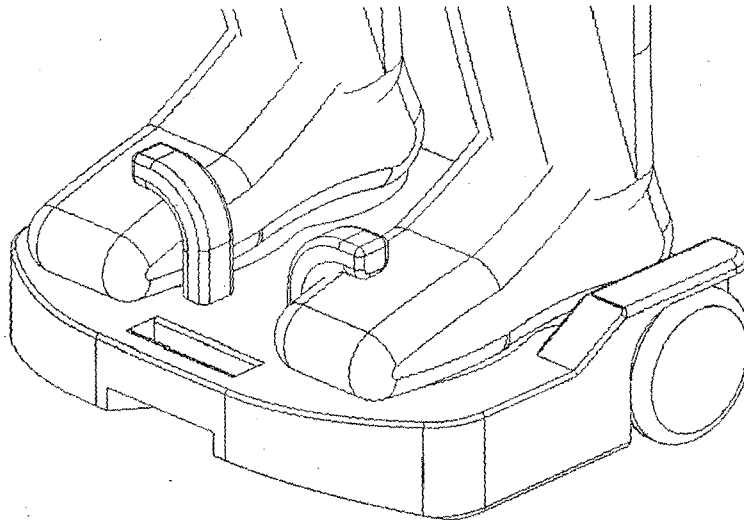


Figure 4

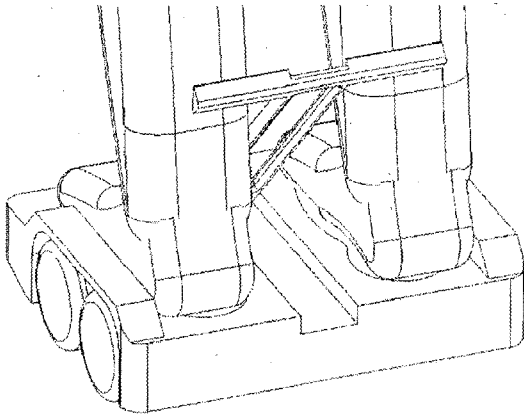


Figure 5A

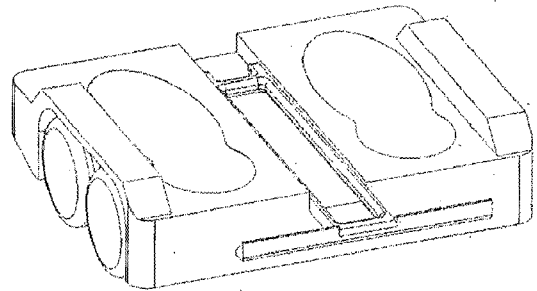


Figure 5B

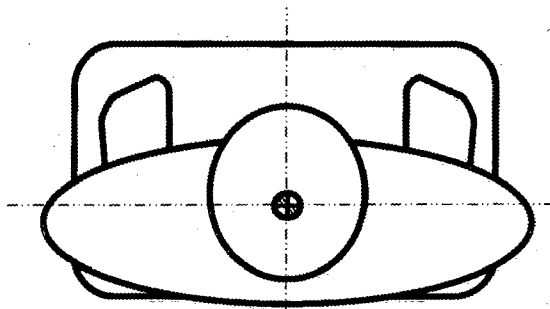


Figure 6A

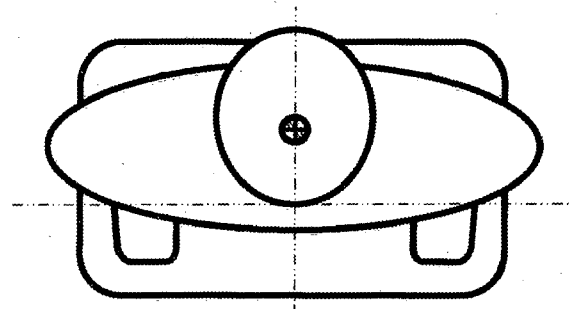


Figure 6B

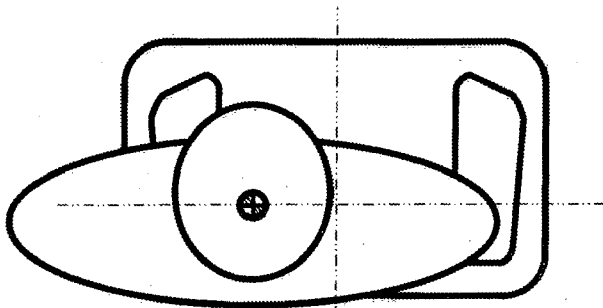


Figure 6C

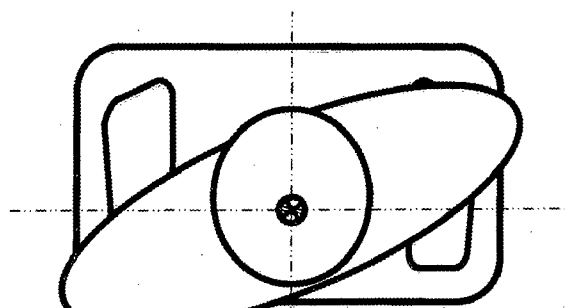


Figure 6D

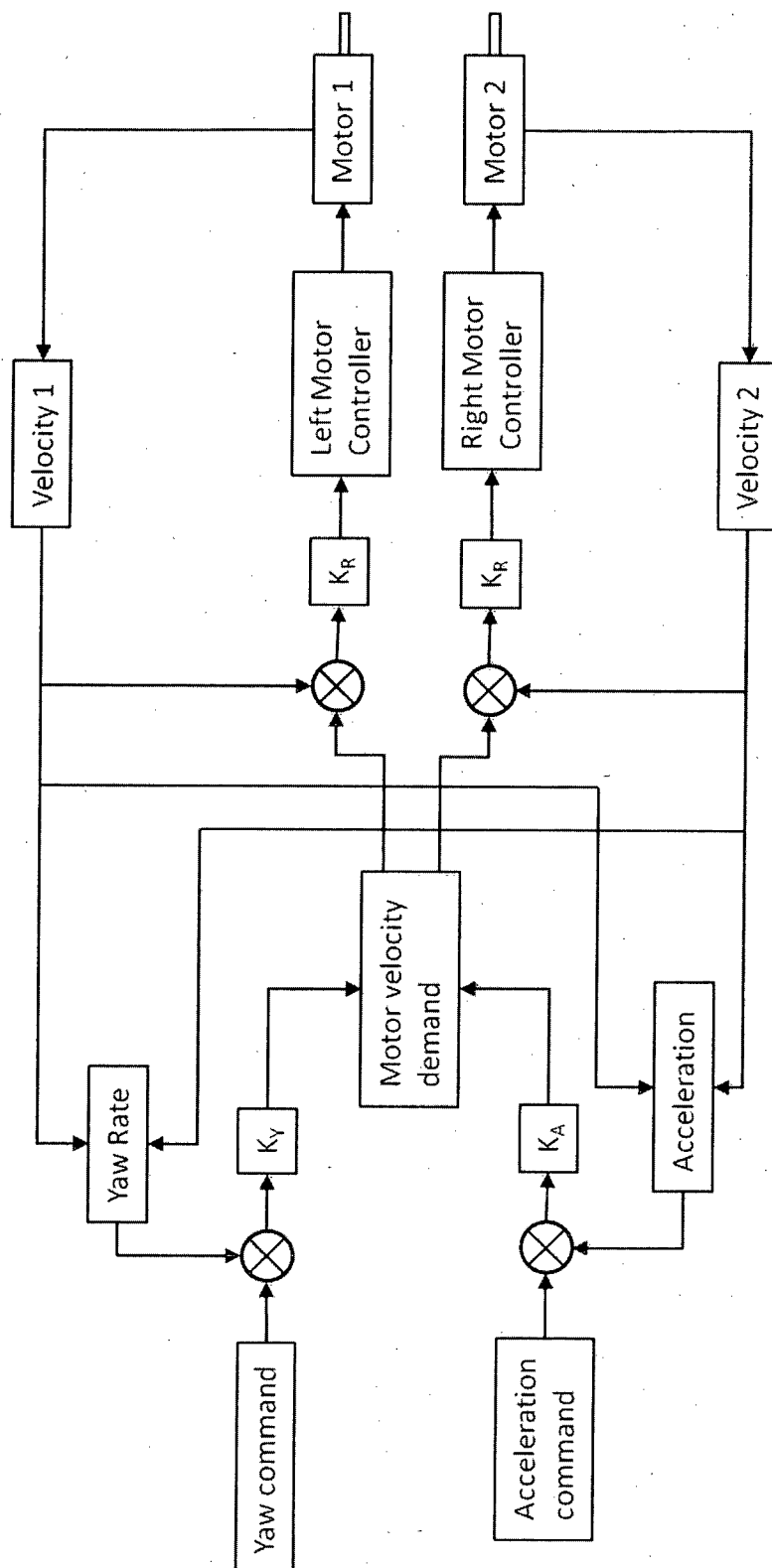


Figure 7

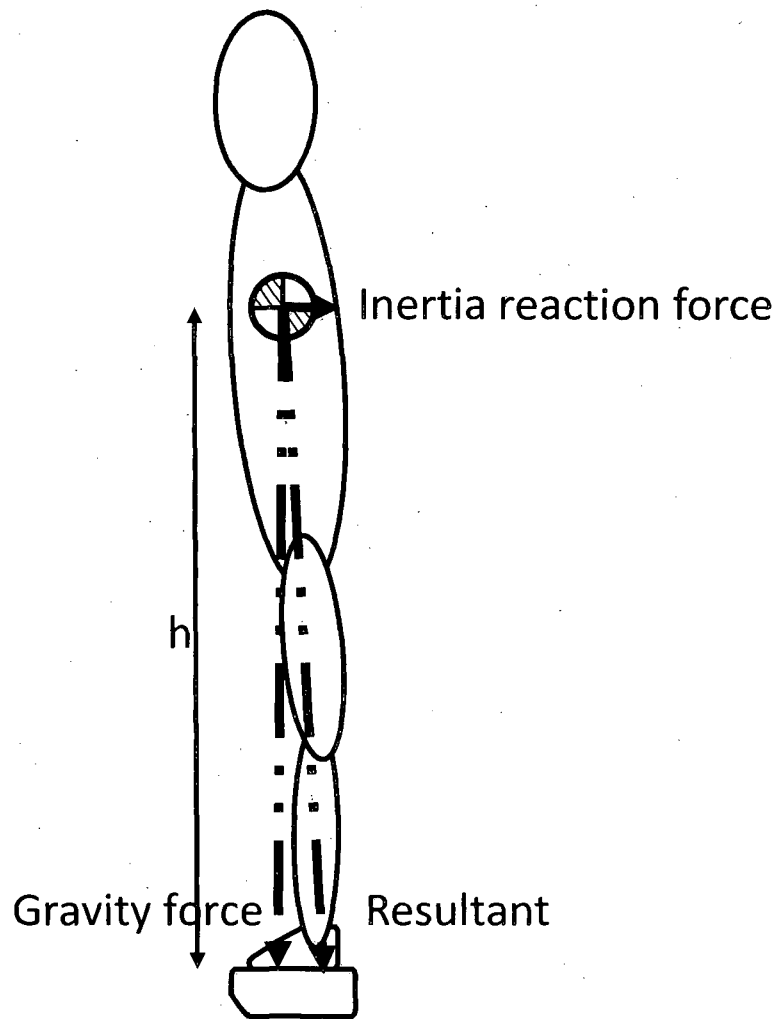


Figure 8