Wa-Chair: A concept for development of economical stair-climbing wheelchair

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Abstract. In this paper, a concept for development of cost effective and reliable stair climbing wheelchair is being proposed. Slider-crank mechanism is being used to compensate for any variation in inclination angle of the wheelchair during ascent or descent on stairs. Controlling wheelchair’s inclination angle can reduce risk for the rider as it prevents the wheelchair from toppling. A prototype is being developed to validate proposed mechanism. Proposed mechanism allows rider to view in the direction of progress which adds additional safety to the rider.

1. Introduction
Physical disability bound to occur in most people if they live longer, as strength of bones and muscle deteriorate after certain age. Unfortunately, for many it happens earlier due to accidents or decreases. Moreover, some are affected by birth. Also, population ageing is one of the concerned issues through out the world. Hence, researches are working continuously towards the development of assistive device for elderly and disabled people. One of the most popular field in development of assistive technology is assistance in commuting people. In this field, wheelchairs had served for a very long period of time and has being evolving continuously. Although electric wheelchairs was one of the benchmark development, climbing up stair is one of the major concerned area.

Researchers had developed track based stair climbing wheelchair which consists of both wheels as well as track belt. Tracks were used for climbing up stairs, whereas wheels were used in plain [1, 2, 3]. Another design was based on attaching a separate module. This is attached to the wheelchair, whenever the rider needs to climb up the stairs [4]. Cluster based stair climbing wheelchair were developed where wheel were replaced by a cluster of three wheels[5, 6, 7, 8, 9]. Moreover, many advance wheelchairs were developed which could balance on two wheels [10].

Most of stair climbing wheel chair available in the market are expensive, complex or bulky. Hence, development of cost effective stair climbing wheelchair is need of present. This paper is organized as follows: Section 2 illustrates about working principle of proposed mechanism; Section 3 explains sensor and filters used; Section 4 presents overview of PID control; Section 5 results of developed prototype and experiments is being discussed. Conclusion and future works are mentioned in section 6.
2. Working Principle

In this section, working principle of proposed mechanism is being explained. Figure 1 shows a schematic of methodologies followed by the system to climb up or down on the stairs. The system comprises of two front and a rear wheel. Diameter of front wheel is bigger as compared to rear wheel. Chair is mounted on front axle and rear wheel is connected to the chair by means of slider-crank mechanism. This ensures controllability of wheelchair’s inclination angle.

In slider-crank mechanism, mechanical parts are assembled in such a way that linear motion is converted to rotary motion or vise-versa. The link which rotate is termed as crank and reciprocating link as slider. With little consideration, it can be confirmed that any wheelchair fabricated using rigid structures will tilt as it climbs up or down the steps. This is because of change in elevation of front and rear wheel. During climbing motion wheelchair will tend to tilt backward whereas it will tilt forward while climbing down the steps. This arises risk for the rider as wheel chair may topple during descent on steps. Although, wheelchair will not topple during ascent motion, but it can tilt to an extent where rider will not be able to see the steps. Hence, use of control system is being proposed to compensate for any change in inclination angle of the wheelchair. This can be achieved by use of slider-crank mechanism. In proposed system, control of inclination angle can be achieved by three methods, i.e., varying actuator’s length or by rotating crank shaft or by controlling speed of rear wheel. Also, for better reliability combination of method can be used.

Figure 1: Schematic of mechanism

Figure 1(a) describes about motion of wheelchair during climbing up the steps. Initially, the inclination angle of the chair is set as \( \theta \) with respect to horizontal plane. As the wheelchair climbs 1st step, elevation of front wheel’s center increase. Red dotted lines represents previous position of rear wheel from which it moves to new position. Final image describes about the situation when both front and rear wheels are on steps. From diagrams it can be noticed that in order to maintain initial angle \( \theta \), length of link BC gets reduced whereas link AB rotates as a crank.

Similarly, in figure 1(b), motion of wheelchair during descent is being illustrated. It can be seen that inclination angle of the wheel chair can be controlled by either adjusting length of link BC or by rotating link AC or by varying speed of rear wheel.

For successful operation of proposed wheelchair, it is important to keep track of wheelchair’s inclination angle continuously. For this purpose MPU6050 is being used. In following section
details of MPU6050 is being discussed.

3. Sensor

3.1. Kalman Filter

Accuracy in sensing is one of the key factor for proper operation of a control system. To make systems cost effective a low cost sensor is being used, but these sensor is found to be less accurate. Kalman filter is one of the most popular stochastic estimation method to estimate correct data from inaccurate sensor [11]. This filter have gained popularity in many research field, especially in the field of autonomous or assisted navigation. Prediction are performed based on three equations of kalman gain, current estimate and new error in estimate. These equations for the Kalman filter is given as:

\[
KG = \frac{E_{est_{t-1}}}{E_{est} + E_{mea}} \\
EST_t = EST_{t-1} + KG (MEA - EST_{t-1}) \\
E_{est_t} = (1 - KG) E_{est_{t-1}}
\]

where,

\( KG \) = Kalman Gain  \\
\( E_{est} \) = Error in estimated value  \\
\( E_{mea} \) = Error in Sensor  \\
\( EST \) = Sensor’s estimate Value  \\
\( MEA \) = Measured sensor value  \\
\( t \) = Iteration number

Figure 2: Flow chart of Kalman filter

Figure 2 illustrates the flow process of kalman filter. Initial error, initial estimate and Error in Measurement is provided manually. Value of Error in Measurement remains unchanged throughout the iteration process. Iterations are performed till data variation falls under predefined limits.
3.2. MPU 6050

Tilt sensors plays an important role in proposed stair climbing wheelchair. The sensor continuously sends attitude of the robot to micro-controller which processes the signals and controls speed of rear wheel accordingly. MPU 6050 sensor consists of a 3 axis accelerometer and a 3 axis gyroscope. Accelerometers and gyroscopes are arranged mutually perpendicular axis. This enables to measure change in three degree of linear and rotation motion, respectively. However, in prototype, two axis of accelerometer and single axis of gyroscope is being used. Figure 3 shows image of the sensor. MPU 6050 uses I2C communication to communicate between sensors and micro-controller.

![Figure 3: MPU 6050](image)

Accelerometer sensors can determine force in terms of gravity in particular direction. Hence, if any axis of the sensor is aligned to true vertical then an output of 1g can be seen on that sensor if it is held fixed. If sensor is tilted, components of 1g will be seen in other axis axis as well, however resultant of all the components will be 1g. This components can be resolved to find the tilt angle. Although, accelerometers are efficient in measuring angles, but these sensors are sensitive enough to pick up small vibrations also. This will cause noise in accelerometer readings.

On the other hand, gyroscopes provides the information of angular velocity. This angular velocities are multiplied by time to derive angular displacement and then integrated to get attitude of the robot. Since, the data is integrated any error in data will also be added to subsequent result. This causes drift in gyroscopic measurements.

Another problem associates with this sensors is that if initially sensor is not perfectly horizontal, gyroscope will assume that angle as zero. Hence, these sensors are incapable of sensing initial attitude. To solve this problem, initially accelerometer data is used to compute initial inclination of prototype. Later, output from complementary filter is considered to compute inclination of the prototype.

3.3. Complementary Filter

To compensated for the error form accelerometers, complementary filter is being used. A large fraction of gyroscope’s data is added to a small portion of accelerometer data to get the final value of tilt angle. Comparison of data generated by accelerometer and using complementary filter is shown in figure 4. The spikes seen in accelerometer data represents the situation when sensor was subjected to movement in horizontal plane only. Since, tilt angle calculation is based on accelerometer data in all direction, results shows change in tilt angle. It can be seen that using complementary filter such noises can be rectified. Although some ripples can be seen on those situations, but those are too small to effect control system of the robot.

![Figure 4: Accelerometer raw data Vs comp. filter](image)
4. Proportional Integral Derivative (PID) control
In developed prototype, proportional integral derivative (PID) controller is being used. Figure 5 shows the flow chart of the control system. Feedback signal generated by tilt sensors are fed to micro-controller, which is continuously computes any deviation from desired inclination angle value. Each terms of PID control represents different types of errors. While deviation from desired output represents proportional part, Integral part represents summation of all the errors in iterations. Derivative parts accounts for errors with respect to previous error. Gains $K_P$, $K_I$ and $K_D$ are multiplied to the proportional, integral and derivative errors respectively. Finally the combined signal is sent as an output to actuators. Following equation are used in PID control system.

\[
E_p = \text{Current Value} - \text{Desired Value} \\
E_I = \sum E_p \\
E_D = E_{P_K} - E_{P_{K-1}} \\
E = K_P \cdot E_p + K_I \cdot E_I + K_D \cdot E_D
\]

![Figure 5: Block Diagram of PID control used in the robot](image)

5. Results

![Figure 6: Ascending on steps](image)  ![Figure 7: Descending on steps](image)
A prototype has been developed to conduct experiments. It consists of two front wheels and a rear wheel driven by geared DC motor. MPU 6050 is being used as a sensor for gathering information of prototype’s inclination angle. To vary inclination angle of the prototype a servo motor was used. Rotation of all motors has been controlled by ARDUINO UNO.

Experiments were conducted with and without control. Figure 6 & 7 are snapshots of experiments. These shows that by controlling inclination angle of the wheelchair, stair climbing can be successfully achieved. It was found that when controls were not used wheelchair was unable to climb up in some instant. In that case a slight push was required for the motion to continue. Also, it was found that by using PID control variation of inclination angle had reduced by 7 and 10 degree while ascending and descending respectively. Moreover, in case of descending without control at one instant the angle crossed true vertical. Such situation should be avoided as this may lead to toppling of wheelchair.

6. Conclusion and Future Work
A novel concept for step climbing wheelchair having two front wheels and a rear wheel was proposed. For safe operation of wheelchair inclination angle is one of the important factors. Hence, variation of inclination angle was controlled with slider-crank mechanism. A low cost tilt sensor was used in combination with kalman and complementary filter to sense inclination angle of the robot. PID controller was used to process feedback signal and fed to actuators accordingly. A prototype was developed and experiments were performed. It was found that proposed system can climb up and down maintaining the initial inclination angle. In future a 3-D model will be developed to evaluate kinematics, dynamics and stability of proposed wheelchair. Finally, a bigger prototype will be developed and experiments will be performed.

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