The Prototype of Assistive Cane for Climbing Up the Stair

Pipatpong Boonthaworn¹, Panya Aroonjarattham¹,* and Chompunut Somtua¹

¹Department of Mechanical Engineering, Faculty of Engineering, Mahidol University, Nakornpathom Thailand 73170

* Corresponding Author: panya.aro@mahidol.ac.th

Abstract

The elder and patient with osteoarthritis knee had the problem to climb up the stair. The purpose of this research was to design and construct the prototype of assistive cane for climb up the stair. The assistive cane use Arduino to control the motor, send the power to the gear set to lift the user up the stair. The lifting plate help to reduce the burden at the knee joint while climbing up the stair. The foot force sensing device used to measure and collect the force act on the insole while walking on the floor, climbing up the stairs and climbing up the stairs using the assistive cane. The assistive cane could be help to reduce the burden at the knee joint and the force on the insole when climbing up the stair.

1. Introduction

At present, Thailand is entering the society of the elderly. According to the Ministry of Social Development and Human Security in 2018, the number of elderly people (over 60 years old) was 16.06 percentage of the total population. The elderly population distribute in Thailand as shown in Figure 1.

![Figure 1](image_url)

Figure 1. The elderly population distribute in Thailand in 2018 [1].

The common problems of the elderly due to knee degeneration include muscle weakness that occurs with the elderly or patients with osteoarthritis who receive physical therapy after undergoing knee surgery. Although there are many currently facilities that helped in the daily life such as crutches and wheelchairs but these devices does not support to climb up the stair. This study aims to design and
construct the prototype of assistive cane to climb up the stair using the lifting plate controlled by Arduino to reduce the burden at the knee joint while climbing up the stair.

2. Materials and Methods

2.1 The conditions and limitations
The main condition is the height and width of each step that has 16.67 cm. height and 26.27 cm. width as shown in figure 2. The symptoms of the tester have a problem with left leg, so the tester can stand by two legs but cannot stand by one leg which painful.

![Figure 2](image)

**Figure 2.** The height and width of stair: \( a = 16.67 \) cm. and \( b = 26.27 \) cm.

2.2 The prototype of assistive cane for climbing up the stair
Three-dimensional model of the assistive cane, which was designed by SolidWorks software, shown in figure 3 and the prototype shown in Figure 4.

![Figure 3](image)

**Figure 3.** Three-dimensional model of the assistive cane for climbing up the stair.

![Figure 4](image)

**Figure 4.** The prototype of the assistive cane for climbing up the stair.
The usability of assistive cane for climbing up the stair has 5 steps as follows:

- First, place the right foot on the plate.
- Second, step left foot up the stairs.
- Next, turn on the prototype of assistive cane to lift up to the same level as the upper stair.
- Then, step right foot on the stairs.
- Finally, drag the prototype of assistive cane onto the stairs.

2.3 DC Motor and Gear

Conditions of the motor’s load are the tester weight 50 kilograms, the height of each step was 17 cm. and the time to move the tester foot to next step was 5 seconds. Three parameters used to calculate the power of motor in equation (1).

\[ P = \frac{F_s}{t} \]  

(1)

Torque of motor calculates by equation (2). The selected motor, 36 watts used to find the size of the rack and pinion.

\[ P = T \omega \]  

(2)

Table 1. Spur gear’s radius calculation

| rpm | \( \omega \) (rad/s) | a (m/s²) | F (N) | T (N.m) | R (cm) |
|-----|----------------------|---------|-------|---------|--------|
| 5   | 0.524                | 0.003   | 522.138 | 68.755  | 13.17  |
| 10  | 1.047                | 0.006   | 522.298 | 34.377  | 6.58   |
| 30  | 3.142                | 0.018   | 522.934 | 11.459  | 2.19   |
| 50  | 5.236                | 0.030   | 523.571 | 6.875   | 1.31   |
| 80  | 8.378                | 0.048   | 524.526 | 4.297   | 0.82   |
| 100 | 10.472               | 0.060   | 525.163 | 3.438   | 0.65   |

From Table 1 at various speeds, the selected motor has an axis size 10 mm. The choosing motor with a speed of 10 rpm has the smallest radius of 6.58 cm. Equation (3) and (4) is used to find the spur gear size [2].

\[ S_p = \frac{S_Y Y_J}{\sigma Y_B Y_Z} \]  

(3)

\[ \sigma = W^t K_s K_i \frac{1}{m_i} K_{m r} K_{t m} Y_f \]  

(4)

\( S_p \) is Allowable bending stress equal to 267.66 MPa.
\( Y_N \) is Stress cycle factor for bending strength equal to 1.08.
\( Y_T \) is Temperature factor for bending strength equal to 1.
\( Y_R \) is Reliability factor for bending strength equal to 0.99.
\( W^t \) is Tangential transmitted load equal to 522 N.
\( K_o \) is Overload factor equal to 1.25.
\( K_{m r} \) is Dynamic factor equal to 1.69.
\( K_s \) is Size factor used equal to 1.
\( m_i \) is Transverse metric module.
\( K_{m r} \) is Load distribution factor equal to 1.453.
\( K_{t m} \) is Rim thickness factor equal to 1.
\( Y_f \) is Geometry factor for bending strength equal to 0.42.
The safety factor of the gear that is commonly used is 1.75. Instead, take the safety factor in equation (3) to find the face width.

\[
S_F = \frac{S_Y}{Y_x} \\
1.75 = \frac{267.66(1.08)}{\sigma(1)(0.99)} \\
\sigma = 166.853 \, MPa
\]

form \( \sigma = 166.863 \)

\[
\sigma = W'K_jK_sK_a \frac{1}{b_{m_j}Y_j} \\
166.863 = 0.522(1.25)(1.69)(1) \frac{1(1.453)(1)}{b} 0.42 \\
b = 0.022 \, m \\
b = 22 \, mm
\]

Finally, the appropriate module for rack and pinion is 2.5, which has a face width of 25 mm by the pinion or spur gear with diameter 12 cm.

2.4 Tri-star wheel

From Figure 5, it has five parameters to design a tri-star wheel. Two known parameters and three unknown parameters calculated by Equation (5), (6), (7), (8) and (9) [3].

\[
R = \sqrt{\frac{a^2 + b^2}{3}} 
\]

\[
r_{\text{max}} = \frac{\sqrt{a^2 + b^2}}{2} 
\]

\[
r_{\text{min}} = \frac{6Rt + a(3b - \sqrt{3}a)}{(3 - \sqrt{3})a + (3 + \sqrt{3})b} 
\]

\[
t_{1\text{max}} = \frac{3r(a + b) - \sqrt{3}r(a - b) + a(\sqrt{3} - 3b)}{6R} 
\]

\[
t_{2\text{max}} = \frac{r\left(r + \sqrt{3}(a^2 + b^2 - r^2)\right)}{2\sqrt{a^2 + b^2}} 
\]

Figure 5. Five parameters on tri-star wheel
2.5 *Electrical circuit*

The circuit including on-off switch, motor, li-on battery, two-ways and limit switch and battery monitor shown in Figure 6.

![Image of the assistive device’s system circuit](image)

**Figure 6.** The assistive device’s system circuit

When switching on, the on-off switch will change from NC to NO as shown in Figure 7 (a). Therefore, the NO of the power switch connects to the battery and supply power to the device system.

![Image of the switch circuit](image)

**Figure 7.** The switch circuit: (a) On-off and (b) Two-ways.

For two-ways switch as shown in Figure 7 (b), the motor rotate clockwise when press the button down. The contact on the left will change from NC to NO, which connect to the motor as well. When the motor rotate counterclockwise, the contact on the left will change from NO to NC and the contact on the right will change from NC to NO, which connect to the motor as well. The limit switch connects in the series to cut off the power when moving to the specified distance.

2.6 *Foot force sensing device*

The foot force sensing device used to measure and collect the force act on the insole while the user walking on the floor, climbing up the stairs and climbing up the stairs using the assistive cane. Six force sensitive resistors installed on the insole as shown in Figure 8.

![Image of the force sensitive resistor and sensors](image)

**Figure 8.** (a) Force sensitive resistor and (b) Six sensors install on the insole.
3. Results and Discussion
The prototype of the assistive cane used to help the people, who had the knee joint problem to climb up the stair. The foot force-sensing device was installed on both insole as shown in figure 9 to measure and collect the force act on the insole.

![Figure 9. The foot force sensing device measure and collect the force act on the insole.](image)

The data from foot force sensing device used to compare between the normal knee and osteoarthritis knee when walking on the floor, climbing up the stairs without assistive cane and climbing up the stairs with assistive cane as shown in Figure 10.

![Figure 10. The tester climbs up the stair with assistive cane.](image)

The tester have problem at the left knee joint was tested under three condition. The forces on insole under walking on the floor were shown in Figure 11 (a) and 11 (b) for left and right foot respectively.
Figure 11. The force on insole under walking on the floor: (a) Left foot and (b) Right foot.

The left foot will receive less force than the right under walking on the floor condition. All sensors show more force acting on the right compared between six sensors on both insole. The maximum force on the left foot occurs at the middle of insole because the tester avoids putting the load on the left and transferring the load to the right. The forces on insole under climbing up the stairs without assistive cane were shown in Figure 12 (a) and 12 (b) for left and right foot respectively.
Figure 12. The force on insole under climbing up the stairs without assistive cane: (a) Left foot and (b) Right foot.

The left foot must bear the load similar to the right under climbing up the stairs without assistive cane condition. The occurring force on the left insole is closely to the right as shown in the graph. The force on insole under climbing up the stairs with assistive cane were shown in Figure 13 (a) and 13 (b) for left and right foot respectively.
Figure 13. The force on insole for climb up the stairs with assistive cane: (a) Left foot and (b) Right foot.

While climbing up the stairs with assistive cane, the force on the left insole reduce from the Figure 12 (a). All sensors show the lower force on the left than the right insole that will be able to reduce the burden on the left knee joint. The sensor that receives the most force is located at the heel and middle of the foot as shown in the graph, which shows that the body weight does not transfer to the front, so in summary, the burden on the knees has been reduced.

In summary, the burden on the knees has been reduced.
4. Conclusion
The prototype of assistive cane can be help the user with the osteoarthritis knee to climb up the stair with the less burden on the knee joint. This prototype device could be used with ladder distance not exceed 17 cm. The design of the mechanism of tri-star wheels can help the users easily drag the underlying device up and down the stairs.

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