# An Inexpensive, Alternative, Drop-off Detection Solution

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## ABSTRACT

Drop-off detection is a problem in wheelchairs which use sensor technology to provide obstacle avoidance features. Tests were conducted to determine whether the Sharp GP2D12 infrared sensor can provide an effective and inexpensive solution. Results indicate that a drop-off detector incorporating the GP2D12 was able to detect drop-offs as shallow as 5 cm.

## BACKGROUND

There have been several different implementations of 'intelligent' wheelchairs, which are able to detect obstacles in the environment and assist with navigation and obstacle avoidance (1,2). These wheelchairs are intended to aid wheelchair users who have difficulty driving a standard wheelchair due to visual impairments, fine motor limitations, cognitive challenges, and other impairments. These devices have focused on detecting upright obstacles, such as walls, furniture, and people. Unfortunately, many of them do not implement any way of detecting drop-offs such as curbs or descending staircases. Such drop-offs can pose a more serious risk of injury than upright obstacles. Those that do implement drop-off detection often use laser range finders (3). Laser range finders are very costly, on the order of several hundred dollars. The authors are working toward a more cost-effective smart wheelchair system that also includes the ability to detect drop-offs.

## RESEARCH QUESTION

The Sharp GP2D12 (Sharp, Romeoville, IL) infrared sensor is able to detect objects at distances between 0.8 cm and 75.8 cm (4). This is consistent with the distance between the floor and the footrests of a wheelchair. Initial tests with various sensor angles indicated that the GP2D12 could discriminate between level ground and a drop-off at sensor angles between 45 and 60 degrees. Further tests were conducted to evaluate this sensor's potential for use as a drop-off detector.

## METHOD AND RESULTS

To be useful, the sensor must be able to detect drop-offs far enough ahead to stop the chair. Tests indicated that a Quickie S-626 power wheelchair (Sunrise Medical, Carlsbad, CA) required 27 cm to come to a stop from a speed of 43.7 cm/s (1.43 ft/s). The GP2D12 was tested to determine how far away it could detect drop-offs. These tests were conducted outdoors on the edge of a 12.7 cm curb, and indoors on the edge of a 96.5 cm drop. In addition to two conditions of drop-off depth, this also represented two lighting conditions; which is important since infrared sensors are light sensitive. The GP2D12 was attached to the footrests of a Quickie S-626 power wheelchair in such a way that the sensor angle could be varied. The voltage response was measured when the wheelchair was on level ground. The wheelchair was then positioned at the furthest distance from the drop-off that resulted in a sensor reading at least 20% lower than the original value, and the distance from the drop-off to the wheelchair's front casters was measured. This test was repeated for two sensor angles ($45^o$ and $60^o$) under each lighting condition. The results, listed in Table 1, show that the detection distance is great enough to provide sufficient stopping distance.

Based on these preliminary results, the GP2D12 sensor was mounted on the power wheelchair. The GP2D12 sensor was mounted on cut wood. The wood was cut at a 45 degree angle and mounted on the footrests of the wheelchair. The sensor itself was mounted with two #6 3/4 inch screws. The result, without a user in the wheelchair, is a sensor angled 55 degrees from vertical and

18.4 cm from the ground. As this device is mounted on the footrests of a wheelchair, the weight of a user's leg and foot will affect the angle and the height slightly. We have found that a user of about 5' 7" and 150 lbs will move the sensor to about 50 degrees from vertical and about 17.15 cm from the ground, which nominally changed the voltage response of the sensor. The sensor angle may need to be readjusted should users with heavier legs attempt to utilize this mounting method.

**Figure 1: Drop-off Detector mounted on an Invacare Action Arrow (Invacare, Elyria, OH)**

| Lighting Condition | Sensor Angle | Detection Distance |
|---|---|---|
| Outdoor | $60^o$ | 45.72 cm |
| Outdoor | $42^o$ | 35.56 cm |
| Indoor | $60^o$ | 46.355 cm |
| Indoor | $42^o$ | 35.56 cm |

*Table 1: Results from the drop-off detection test. Distances were measured from the front caster to the edge of the drop*

The GP2D12 was powered by a 5 V voltage regulator (PT5101N, Texas Instruments, Dallas, TX) and monitored by a laptop computer (Gateway 2000, Poway, CA). Two Data Acquisition cards (DaqCard 1200 & 6024, National Instruments, Austin, TX) intercepted joystick signals, captured the GP2D12 voltage response, and sent output signals to the wheelchair motors. A Visual C++ (Visual C++, Microsoft, Redmond, WA) program was written to compare the GP2D12 voltage response with a given threshold and prevent the wheelchair from moving forward if the sensor's voltage response fell under the threshold. This threshold was selected to distinguish between level ground and a drop-off, based on results from previous tests.

On level ground and without a user in the wheelchair, the voltage response from the sensor was about 0.9 volts. When a user was seated in the wheelchair and had their feet in the footrests, then the voltage response increased to about 1.0v due to the change mentioned previously.

The wheelchair was placed on a 1.8 m x 2.4 m platform. With one of the investigators driving the chair, it was backed up as far as possible and he attempted to drive off the platform with full forward speed. The maximum distance traveled was 81.3 cm, and the resulting speed prior to drop-off detection was 43.7 cm/s. The platform was approximately 10 cm from the ground, and the GP2D12 sensor with a threshold of 0.6 volts was able to detect the drop-off.

To test less drastic drop-offs, 2.5 cm thick cubicle sidings were placed in front of the platform. With one cubicle siding, the effective drop-off was reduced to about 7.5 cm. During this trial, although the drop-off was detected in the sensor, it did not fall sufficiently below the threshold to stop the wheelchair. After modifying the threshold to 0.8 volts, the drop-off was detected, the threshold was met and the wheelchair stopped in time to prevent driving off the platform. To further test the drop-off detector, we placed another cubicle siding which reduced the height to about 5 cm. After running another trial, it was determined again that the drop-off was seen but did not meet the thresholds. Adjusting the threshold up to 0.9 volts allowed the system to detect the drop-off and prevent falling from the platform.

## DISCUSSION

Based on the results of these tests, the GP2D12 appears to be an effective practical solution for wheelchair drop-off detection. It was able to stop a wheelchair using a relatively simple algorithm and setup, and it was able to detect drop-offs down to 5 cm. This is most likely, the smallest drop-off that is practical to detect with this system. Since the GP2D12 can be purchased for about $14, it is a far more cost-effective solution than a laser range finder.

The detection distance recorded in Table 1 may limit the maximum wheelchair speed for safe driving. With a detection distance of 45 cm and a sensor update rate of 10 Hz, the wheelchair could travel at 450 cm/s (14.8 ft/s) if the wheelchair were able to stop instantaneously. However, the wheelchair's deceleration time must also be taken into account. At a speed of 43.7 cm/s, the Quickie S-626 required 27 cm to come to a complete stop, so the warning provided by the detector would be sufficient at this speed. The deceleration rate was not controlled in this experiment. Further experiments at the wheelchair's maximum deceleration rate and various speeds will indicate the maximum safe speed for which the wheelchair can be used.

Recent testing of the Sharp GP2Y0A02YK sensor has shown it to have a longer range than the GP2D12. It may therefore be possible to detect drop-offs at a greater distance, allowing for faster wheelchair speeds. It may also be possible to move the drop-off sensor to a higher position, for situations in which it is impractical to mount the sensor to the footrests.

It is most important for a drop-off detector to avoid false negatives – instances where the detector fails to recognize a drop-off. It is also important to minimize false positives – instances where the detector interrupts wheelchair movement when there is no drop-off. To test for false-positives, an Invacare Action Arrow wheelchair (Invacare, Elyria, OH) was allowed to travel autonomously within a 4.5m x 4.3 m enclosed area with a flat floor while the voltage signal from the drop-off detector was recorded. The sensor did not incorrectly detect any drop-offs in one hour of testing. Further testing on more varied terrain will provide a better indication of the detector's false positive rate.

One limitation to this system is the assumption of continuous level ground after a drop-off. Should the user of a wheelchair attempt to cross over a small but deep hole in the ground, the GP2D12 may see the other side of the hole, assume that everything is flat and permit the client to continue driving forward.

**REFERENCES**

1. Levine S, Bell D, Jaros L, Simpson R, Koren Y, Borenstein J. (1999). The NavChair Assistive Wheelchair Navigation System. *IEEE Trans on Rehab Eng.* 7(4):443-451.
2. Yoder J, Baumbartner E, Skaar S. (1996). Initial Results in the Development of a Guidance System for a Powered Wheelchair. IEEE Tran on Rehab Eng. 4(3):143-151.
3. Prassler E, Scholz JS, Strobel M. (1998). MAid: Mobility Assistance for Elderly and Disabled People. Proc. 24th Annual Conference of IEEE Industrial Electronics Society. 2493-2498
4. LoPresti EF, Simpson RC, Miller D, Nourbakhsh I. (2002). Evaluation of Sensors for a Smart Wheelchair. *Proceedings of the RESNA 2002 Annual Conference.* pp. 166-168.

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