BREAK Wheelchair Vacuum Project

For Tri-Valley Developmental Services

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Background/Motivation

The subject is confined to a power wheelchair due to his medical condition of cerebral palsy that severely limits his ability to work and marketability in the workforce. He is currently employed through Tri-Valley Developmental Services; and prior to acquiring his current wheelchair, he utilized a scoop attached to his chair to push bags of shredded paper to a collection site. His new wheelchair, however, will not allow for the attachment of this scoop. In order to provide more employment opportunities, it has been proposed that a vacuuming unit be designed to attach to his wheelchair, allowing him to provide cleaning services for different offices and other businesses. It is the goal of the team to design a system that will allow him to be more marketable in the workforce, and to design the system such that it will be adaptable to multiple types of chairs to avoid the subject's previous predicament . This will also allow the unit to be marketed to others in similar situations.

Design Criteria

The team started the design process by meeting with the client and determining what design features were most important. From the feedback we received, customer requirements were derived. The highest priority customer requirements are listed here and a full list is provided in the appendix [A1]:

- The device must be able to vacuum carpet and hard surfaces.
- The device cannot limit the maneuverability of the wheelchair.
- The device must function for a full workday as necessary.
- The device must run on its own power supply.
- The device must match the cleaning power of a commercial vacuum.
- The device should be able to pick up at least 80% of the debris on both hard surfaces and carpeting.
- The device must weight less than to 35 lb. for mounting purposes

- The chair must be able to maneuver through 33” wide gaps/doorways with the unit attached.
- Batteries must last for 2 hours of continual use or be easily replaceable with a charged battery to allow for continuous use of vacuum.

Design Summary

For portability and maneuverability, it was decided to focus on battery-powered options. While several battery powered vacuums are commercially available, all of them were developed for short-duration household cleaning. The customer required that the design be comparable in suction power to a commercial vacuum and have sufficient battery life to last for a two hour workday. Commercial vacuums typically have a volumetric flow rate of 130 cubic feet per minute (cfm). To match this flow rate, leaf blowers that offered vacuuming capabilities for lawn use were investigated. Only one product met our requirements, the Greenworks 40V G-Max DigiPro. This blower provided a maximum volumetric flow rate of 350 cfm and utilized large capacity and a high voltage battery system that provided a manufacturer's quoted runtime of 30 minutes. With the exception of runtime on a single battery, this blower exceeded our design specifications in every area.

Slight modifications were necessary in order to adapt the blower to vacuuming in an indoor space. First, a fine particle filtering bag system was added to the output. The rectangular outlet fitting on blower was heated and molded to fit a 2.5-inch PVC elbow. The outer support bag (Figure 1) from a Sanitaire commercial upright was slightly modified and secured around this elbow. Several options were investigated for a filter bag, with the team ultimately deciding on a type RR Eureka bag, which can be purchased at most major retailers. This bag is ideal for the design because it has a top fill inlet that friction fits onto the PVC elbow. The outer bag is secured to the 80/20 frame by a set of toggle clips and nylon straps.

Figure 1. Sanitaire outer support bag and Eureka RR disposable insert.

The 5-inch suction port on the blower unit needed to be necked down in order to allow connection with a standard vacuum hose. Initially, the team purchased several off the shelf reducers to allow the vacuum unit to connect with a standard 2.5 inch Shop Vac hose. After testing the device with this reduction system in place, the team noticed that much of the debris cleaned from the floor was accumulating in the reducers rather than being transferred through the unit into the collection bag. The problem was being caused by the large drop in air velocity as it expanded through the system of reducers allowing debris to fall out of the air stream. In order to remedy this, it was decided that the reduction needed to take place in one step as close to the suction inlet as possible. A custom inlet tube was constructed from sheet metal and a 2.5 inch metal pipe section (Figure 2). The system was tested with the new reducer and the problem was solved. After a test fitting of the system on the wheelchair, it became apparent that the 2.5 inch hose did not allow for bends with a tight enough radius to be used on the final design. A 1.25 inch hose was purchased and an off the shelf adapter was purchased to allow for fitting to the inlet adapter.

Figure 2. One step reducer from a 5 inch tube to a 1.5 inch tube.

The forward-mounted suction nozzle was the next area to be addressed. The nozzle was required to be sufficiently wide to provide an adequate cleaning path but not so wide as to impede the maneuverability of the wheelchair. The wheelchair's footplate is 11.25 inches wide at its widest point and the overall width of the wheelchair is 24 inches. As the vacuum system will be used on carpeting and hard surfaces it was determined that the nozzle must also contain a carpet agitating brush in order to properly remove debris from the carpeted surfaces. Once again several commercially available nozzles were investigated and the Vacuflo Turbocat was selected (Figure 3). The Turbocat provided a 13.5-inch wide cleaning path, was air turbine powered, and was easily adapted to multiple vacuuming systems. The 13.5-inch wide cleaning path is wider than most cleaning nozzles while still being narrow enough to prevent impeding the wheelchair's maneuverability. The nozzle was designed to be used with home central vacuuming systems with typical volumetric flow rate of 130 cfm. During the testing period of the design, the nozzle was easily jammed by larger materials and would not be sufficient for cleaning

the concrete shop floors at Tri Valley. The team decided to provide an additional nozzle without a rotating brush. A hard floor nozzle by RIGID was decided to be the best option to fill this need (Figure 3).

Figure 3. Carpet nozzle with air-driven beater brush (left) and hard floor nozzle (right).

In order to create the frames to mount the system to the wheelchair, 3D models were created of the components. AutoDesk Inventor 2013 was utilized to create a full model of the Invacare FDX power wheelchair, the Greenworks Blower, and the 80/20 frame (Figure 4). Dimensions for the modeling process were taken on-site or derived from manufacturers' sales information. Eventually, the entire vacuum unit was modeled, which allowed the team to make design decisions with a better idea of spatial constraints.

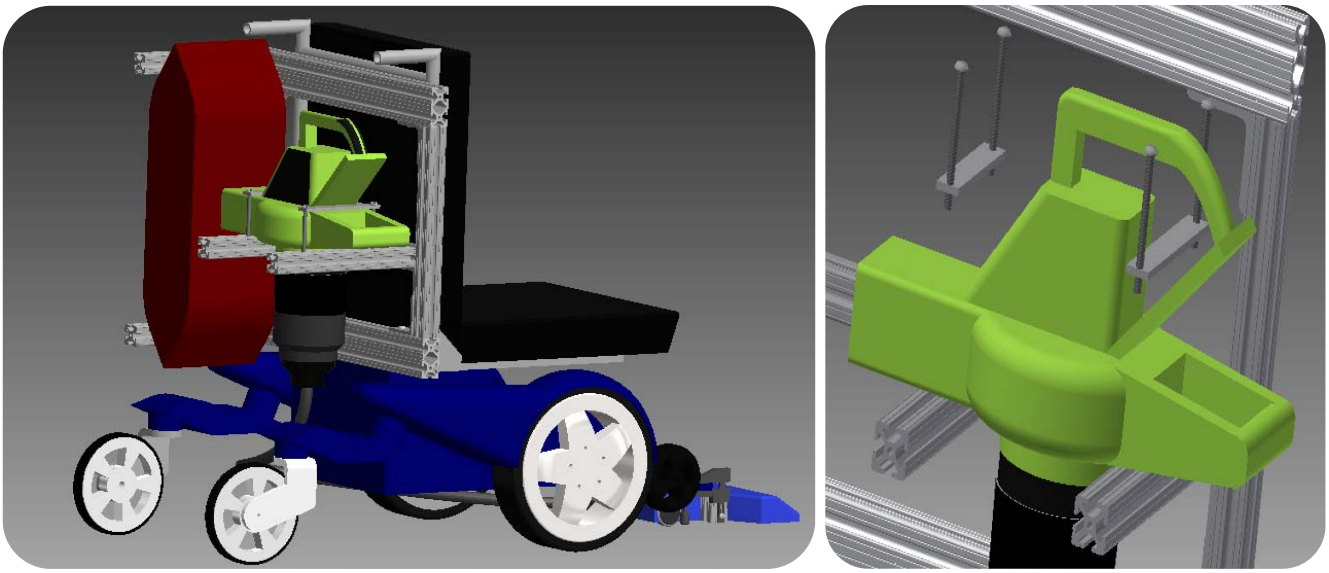

Figure 4. CAD of wheelchair, 80/20 aluminum frame and vacuum attachment (left) Close-up of vacuum mounting system (right).

The spatial requirements of the back of the wheelchair seat required that the frame, which would act as the interface between the vacuum system and the wheelchair, be no larger than 18 inches wide and 18 inches tall. The frame is also required to be as lightweight as possible to limit the amount of exertion required to mount it to the chair and minimize the impact of the weight on the wheelchair's functionality. With a target of well under 100 pounds total for the weight of the entire unit, it was decided that aluminum would provide the greatest strength and machinability while also keeping the total weight of the system at a minimum. In order to allow for adaptability to multiple models of wheelchair, extruded aluminum bars of 80/20 were selected as the main construction material. The T-channels in each face of the 80/20 combined with manufacturer's angle brackets and T-nuts allowed for quick assembly and adjustments that could be made quickly with basic hand tools. This frame will be hung from the wheelchair's handles by nylon loops which will be hard mounted to the top of the frame. This will prevent side to side motion while the wheelchair is operated as well as holding the frame tight to the back of the chair. Rubber bumpers were then added to the extruded pieces of 80/20 to prevent any damage done to walls when coming in contact with the frame.

Our initial nozzle mounting design called for the use of F-clamps and 80/20. It was decided that this design would be too rigid to allow the nozzle to track properly along the floor and ultimately reduce the cleaning effectiveness of the nozzle. The next iteration of the nozzle mount used 3 cam buckle straps attached directly to the top of the nozzle and tightened around the foot rest of the wheelchair to secure the nozzle. While this configuration did allow for proper function, during the testing period the system was found cumbersome to remove and install. The final iteration of nozzle mount returned to 80/20 as the basis of the design. A horizontal bar of 80/20 and two short 80/20 uprights were cut and attached. The 1.25 inch hard plastic end of the Shop Vac hose was secured to the horizontal 80/20 by a steel conduit strap. The entire frame was mounted to the footplate through the use of a toggle clamp on the left upright and an L bracket on the right upright as shown in Figure 5.

Figure 5. Nozzle mounting system (left) for attachment to the wheelchair footrests (right).

Finally an on/off button (that can be used as an emergency stop button) was added to allow Russell to power the unit on/off as necessary (Figure 6). This external momentary button was connected to the momentary power button on the handle of the blower in parallel, which allowed either of these buttons to power the unit on or off. The button was chosen to have a very low operating force

necessary to activate it. It was mounted to the side of the joystick by Velcro to allow the user ready access, even with limited arm and hand mobility.

Figure 6. Low-force momentary switch (left) for powering the vacuum unit on and off (mounted, right).

Budget

The largest costs were the purchases toward the main components of the product -- the GreenWorks blower/vac, extra batteries to accompany the vacuum, the air-driven brush nozzle, and the 80/20 aluminum for the frame. These in total cost $983.57, taking up the bulk of expenses. Minor expenses consisted of hardware for attaching, extra vacuum bags, and other miscellaneous items, totaling $114.42. This brings the total cost of the project to $1097.99.