Investigating and Designing Alternative Solutions for Powered Wheelchair Systems

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ABSTRACT

This project designs around viewing powered wheelchairs as a set of interconnected systems. Alternative solutions are being tested to improve the range, weight, and safety of current models. The methods tested include an internal combustion engine, a system of hydraulics, and advanced control system. An engine provides an alternate power source, extends the range of wheelchairs, and reduces weight. The hydraulic system transmits power to all suspension and steering actuators, as well as a hydraulic motor that propels the wheelchair. The control system involves an IQAN controller area network to integrate the power and hydraulic components with user and sensor input to satisfy a variety of user requirements. Using this design process allows for the evaluation of these alternative systems for powered wheelchairs.

Keywords

system design; hydraulics; internal combustion engine; powered wheelchair; control system

BACKGROUND

The importance of creating better powered wheelchairs is stressed by the increasing amount of users. An estimated 155,000 Americans use powered wheelchairs and another 145,000 use scooters, according to a study performed in 2001 by the Disability Statistics Center (1). The number of users is growing at a high rate, with an over 90% increase in the last decade. Although an aging population accounts for some of this increase, another important factor plays a part. Wheelchairs have become more acceptable and available to a larger percentage of the population needing this assistance due to improvements made in all aspects of wheelchair design and technology.

Many different types of powered wheelchairs are available on the market presently. Though advancements have been made, these wheelchairs have limitations associated with how they provide mobility related to the personal freedom of the user, as well as their safety and health. Most use an electric motor which runs off large batteries and use a four or six wheel design, with ranges of 10-25 miles and battery charge times of 8-14 hours. Every day use power wheelchairs weigh around 150-200 lbs for indoor models and 250-300 lbs for indoor/outdoor versions, with heavy duty models reaching 350 lbs.

Improving power wheelchairs goes beyond the mobility of its user. The wheelchair must provide safety, stability, and comfort while being used. However, accommodating for these concerns usually adds undesired weight to the chair. Additionally, the control strategies for powered wheelchairs and their components are outdated and underdeveloped (2). Current wheelchair design methods do not address the problems developed by the system as a whole.

PROBLEM STATEMENT

System design and application of design science is needed to develop and evaluate alternative powered wheelchair systems to address improvements in power and range, reduced weight, integrated control systems, enhanced wheelchair dynamics including stability, and safety, including occupant protection.

METHOD

The set of systems comprising a powered wheelchair were considered together so that the solutions would cover a broader range of problems. The separation of these systems by functionality resulted in the following: frame and suspension, power, control, seating, and safety and usability. Each system addresses specific areas, but all are strongly interconnected.

The research performed involves an internal combustion (IC) engine, a system of hydraulics, and an advanced control system with an integrated joystick all being implemented on a prototype frame. User feedback has been encorporated into the prototype through quarterly meetings throughtout the design process. Some initial research and design was also done with respect to seating systems and safety and usability systems. The IC engine greatly extends range, enhances dynamic performance, reduces wheelchair weight, and adds the use of fuel as an energy storage mechanism, while the hydraulics system modifies the adjustment capabilities, drive mechanism, and method of power transfer for the wheelchair. The control system would bring these two systems together to work as one integraded system with joystick operation. Each of these systems was developed to assess how well they improve the powered wheelchair system when integrated together.

FRAME AND SUSPENSION

The current frame and suspension system being analyzed and developed is shown in Fig. 1. The prototype has been constructed with this configuration, utilizing hydraulic actuators for height adjustment and steering. The design is a result of much research and conceptual evaluation of alternative systems. A significant reduction in weight (by a factor of 4) is achieved, while incorporating rehabilitative features such as tilt. Height actuation is provided by cylinders controlling the suspension at each of the three wheels, allowing for separate adjustment of the right and left sides, as well as overall height in raised and lowered positions. A rotary actuator controls the direction of the chair through 180 degree rotation of the rear wheel.

POWER

Several considerations were made when determining how to alternatively power the wheelchair. The current design involves a hybrid electric system integrated through a system of hydraulics. Two pumps supply the hydraulic system with pressure; one runs off of the IC engine, and the other off of fast recharge batteries. The interconnection of these systems allows for them to work in congruence. For example, if the pump attached to the batteries is run in reverse by way of the pump attached to the engine, it acts as a generator, charging the batteries. Also, when starting the engine, the pressurized system supplies power to crank the shaft.

Current power methods mostly revolve around the use of a lead acid battery, which is limited by its low service period, high weight, and battery recharge time. Implementing an IC engine into the advanced powered wheelchair as an alternate power source will reduce required battery power, extend range, and reduce weight because the energy densities of fuels are much higher than that of batteries. A high performance lead acid battery has an energy density of 0.14 MJ/kg, and propane and gasoline reach 49.6 and 46.4 MJ/kg respectively (3). Out of the possible fuel sources, propane was chosen because when used in an engine with an oxidizing catalyst, it has been shown to meet indoor air quality standards. Many other propane-powered devices, such as forklifts, floor buffers, and generators are used indoors, showing potential for this IC engine. Additionally, the gaseous properties of propane make it useable in adverse temperature conditions, which will be important if the chair is to be used in various outdoor environments.

The two pumps mentioned above supply pressure to the hydraulic system, which powers all the suspension and steering actuators, and runs a hydraulic motor connected to the rear wheel. The rear wheel acts not only as the steering, but also as propulsion. The capability of hydraulics to easily direct large amounts of power to components on the wheelchair made them an excellent choice. No additional shaft coupling or electrical motors are needed with this design. The hydraulic system will also be able to store energy and act as shock absorption, both of which are further improved with the implementation of an accumulator. Since the actuators are part of the suspension system, all bumps and impacts seen by the wheel will be lessened by the compression of the hydraulic fluid.

FRAME, SUSPENSION, AND POWER RESULTS

Two separate test stands were constructed, on for the IC engine and one for the hydraulic and controls systems. The goal is to fine tune each system before combining them according to the design described above. A prototype frame was also constructed to test hydraulic components on.

- A Honda GX31 engine was used because of its small size and flexibility to customize based upon customer needs
- The engine was converted into a propane fueled engine with the use of a MicroSquirt controller and fuel injector
- Through various sensors, MicroSquirt monitors exhaust O2 content, manifold air temperature and pressure, and engine rotational speed, and controls injector pulse width
- Engine performance is monitored by MegaTune software which is programmed to adjust parameters and run efficiently
- A dynamometer is coupled with the engine shaft to measure the power output
- The three height adjustment actuators, steering actuator, and hydraulic motor are all mounted on the prototype chair
- The hydraulic system is completely plumbed, with fluid power supplied to each component on the chair

FRAME, SUSPENSION, AND POWER PERFORMANCE

Once constructed, each system was tested for functionality.

- Engine currently produces 0.6 hp at 4500 rpm, but with further fine tuning it should produce 1 hp at the same speed
- The engine weighs less than 10 lb
- Engine noise level reported by the manufacturer is around 55 dB, showing that there is room for improvement on the current prototype
- Hydraulic components are supplied with varying pressures depending on need, thus reducing overall power consumed
- The hydraulic motor allows wheelchair to move at moderate speed
- Height adjustment actuators allow for a vertical adjustment of 5 inches
- Steering actuator is able to turn 180 degrees

Each system has some additional testing that is needed. The frame and suspension need testing with various user weights. For the engine, various speeds and loads need to be tested before implementation on the wheelchair. For emissions, a catalytic converter will be installed and a CO sensor is needed. After more evaluation, the entire system will need to be miniaturized to fit on the chair.

CONTROLS

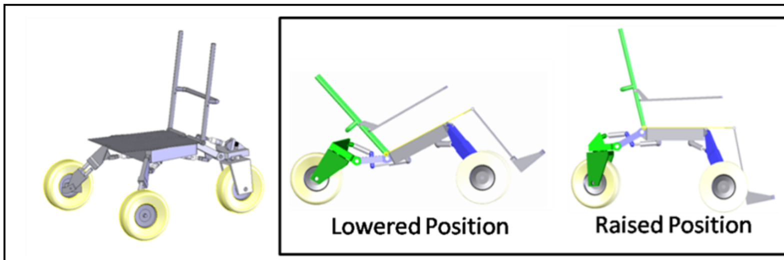

Fig.1: Advanced wheelchair frame design integrating tilt functions with dynamically controlled suspension

The controls system integrating the function of both the combustion power components, hydraulics components, sensors, and user input has been designed to meet the requirements and challenges of the prototype wheelchair by using flexible, easy to program and rugged components so that several iterations of designs could be tested with minimal alteration of the controls system. Using consumer off the shelf (COTS) components further simplifies the construction of the prototype controls system so that sensors, user input devices, and controllers only need to be selected from a range of options rather than designed and programmed from scratch. Once the prototype system has been thoroughly tested and mechanical and hydraulic components decided on for manufacture, a greater design effort can be made on the controls system to reduce manufacturing cost and system complexity. The IQAN system of controllers and sensors offered by Parker-Hannifin Corporation offer a wide range of options for the current prototype build, and features a relatively simple user interface for programming the system. The system will use a combination of a MC2 master and a XS2 expansion controller module to provide a wide range of digital and analog input and output options, and can be strung together with additional expansion controller modules using the IQAN Controller Area Network (CAN) if necessary as the prototype system is tested. A 2-axis IQAN compatible joystick running on the same CAN is used to provide user input to control the wheelchair, and features additional button inputs for activating axillary chair features such as the height adjustment, internal combustion engine status and engine throttle for testing. Sensors are also connected into the control system to monitor chair status such as acceleration, 2-axis chair tilt, wheelchair speed, and hydraulic and propane system pressure to ensure the user is operating within the safety envelope of the chair, and to provide user feedback on the levels of stored energy in the wheelchair available to the user. For maximum wheelchair range independent of other power sources, the pressure in the propane tank is monitored correlating to tank fill level, while the hydraulic accumulator and battery levels are monitored for quiet indoor or low-motion use. Fig. 2 demonstrates how the control system interconnects with various other components on the prototype wheelchair.

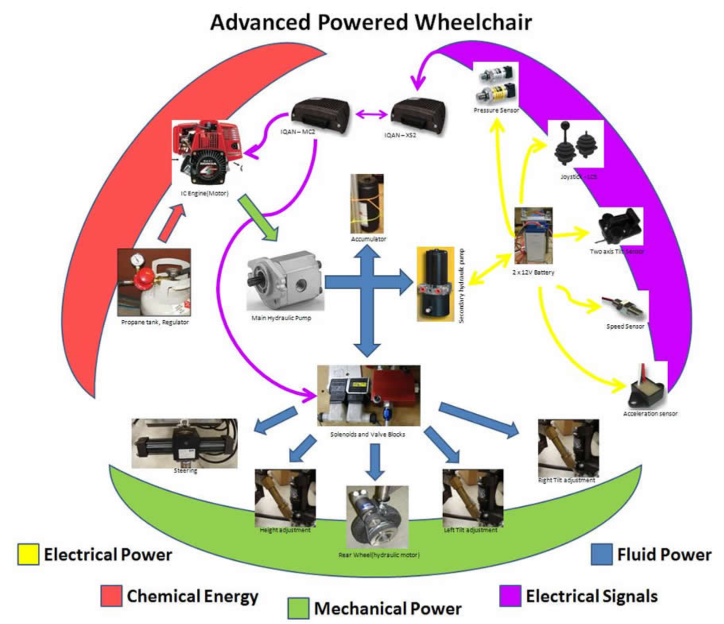

Fig.2: The engine powers the hydraulic system through a hydraulic pump and two controllers control the hydraulic system to move the wheelchair

OTHER FUTURE WORK

Continued research and work is needed to finalize the seating system, and to miniaturize and compact the wheelchair systems into a safe form-factor. Tilt and height adjustment have been built into the hydraulics , and design concepts have been sketched of possibly seating systems as shown in Fig. 3. Future work regarding the seating system will focus on rehabilitative features, user comfort, and safety by integrating elements such as wheelchair occupant crash

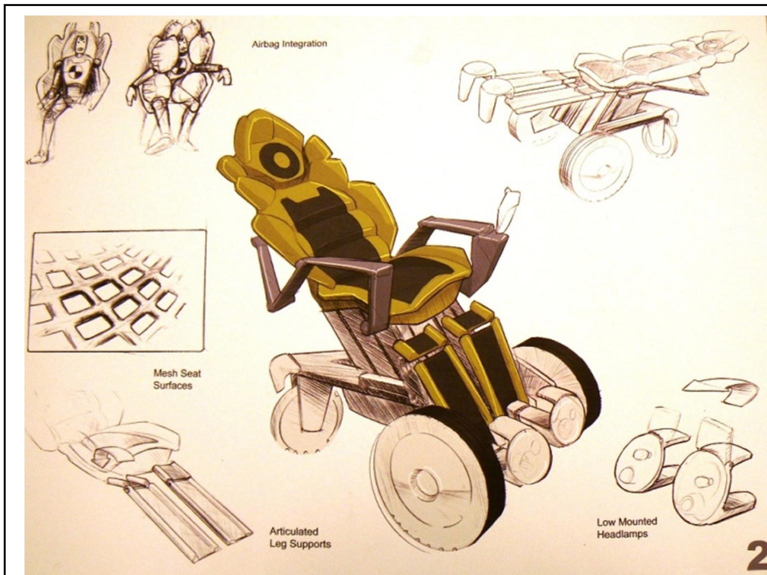

Fig.3: A conceptual design of the future powered wheelchair system

protection, prevention of skin breakdown, and occupant heating and cooling. The current prototype utilizes two test stands for engine and hydraulics testing, and after thorough testing components must be optimized for size and weight considerations in the final chair. Finally, later iterations of the chair must focus on safe operation and transportation including using a safety-dominant control system that dynamically adjusts the chair performance based on current user position, speed, and environmental conditions, enclosing and isolating the engine for fire, climate, and hearing protection, and include quick-disconnect points for all systems to easily break the chair down into lightweight sub-assemblies for transport.

COST

The total cost of the current APW test platform is approximately $6300. The controls system is estimated to be $2000, which includes the sensors, controllers, joystick, and other components. The cost of the hydraulics system including hydraulic pumps, hydraulic motor, actuators, and other miscellanious hardware is approximately $2500. For the power system the estimated cost is $1740, which includes the engine, battery, sensors, solenoids, and engine control computer. This is an unrealistic cost for a consumer chair, but when components have been optimized and designed for manufacture retail costs are expected to be much lower.

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