DEVELOPMENT OF CAD SOFTWARE FOR WHEEL CHAIR DESIGN

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ABSTRACT
Anthropometric data of Nigerian paraplegics was used to design wheel chair for the paraplegics. This was done by developing suitable software using Visual Basic, AutoCAD, Access and Corel-Draw programs. The software developed is capable of designing an ergonomically viable wheel-chair for any category of paraplegic using their anthropometric data within 2 minutes.

Keywords: *CAD, Wheelchair, Paraplegics and Design*

INTRODUCTION

Manufacturing had never been made easier until the development of the Computer Aided Design (CAD) systems, which refers to the use of computer system to assist in creation, modification, analysis or optimization of design (Adejuyigbe, 2002). The CAD system, when integrated with the Computer Aided manufacturing (CAM) fully defines a manufacturing concern devoted to quality and standard product manufacture.

The wheel chair which serves as mobility aid for paraplegics usually comes in several sizes for variety of users. The variation in sizes will ensure that the wheel chair serve several anthropometry classes of paraplegics. The design and manufacture of the wheel chair for the variation in sizes will be easily achieved when CAD/ CAM system is utilized. CAD is defined as the use of computer system to assist in creation, modification, analysis or optimization of design (Adejuyigbe, 2002). Wheelchair is a movable chair, which is used by a person who is unable to walk or move. Wheelchair is used more often by disabled people, but most times people who have illness also use Wheelchair. Anthropometry is the measurement of certain parameters of human body (WHO, 1995). Paraplegics refer to people in a condition where their lower half is paralyzed and cannot move. It is usually the result of spinal cord injury or a congenital condition such as spinal bifida, but polyneuropathy may also result in paraplegic conditions (Wikipedia, 2006). Many paraplegics in Nigeria use wheel chair either donated to them by non-governmental organizations or bought out from stores. However, anthropometric consideration was not utilized before selection of the wheel chair. Ditto, at the point of manufacture, these wheel chairs which are mostly imported were not manufactured with regards to Nigerian paraplegics' anthropometry. In this situation, ergonomics of the wheel chair is usually very poor for the user causing secondary deformities. Secondary deformities occur in paraplegics due to unsuitable wheel chair use and so this study will make manufacture of various sizes of wheel chair possible for different users to checkmate these occurrences. Thus, it will be possible to obtain suitable wheel chair for users based on their body sizes or anthropometry. Manufacturing globally has taken a new trend with the introduction of the Computer aided design (CAD) and computer aided manufacturing (CAM). Thus manufacturing of wheel chair should not be an exception. Typical CAD software to manufacture wheel chairs with consideration to the Nigerian paraplegics' anthropometric data needs to be developed. Hence the objective of this research work centered on the development of suitable CAD software to design wheel chair for all categories of paraplegics. This work will help to achieve an easier, faster and more accurate means of designing the wheel chair based on the CAD system. This will aid manufacturers using computer aided manufacturing (CAM) to produce better wheel chairs for paraplegics. The flexibility advantage offered by CAD/CAM system will allow the development of wheel chairs to accommodate different anthropometric groups.

The wheel chair is one of man's earliest inventions; therefore there is no precise date as to its manufacture. It has the first record of combining wheel to furniture in 530 B.C. (Sawatzky, 2006). But a few one-of-a-kind wheeled chairs apparently were built during the 1600s. Wooden wheelchairs were in use in the United States by the l860s, and the first modern wheelchair--a lightweight folding model--was designed and marketed in 1932 simultaneously by Sam Duke and by the team of Harry C. Jennings, a mechanical engineer, and Herbert Everest, an injured mining engineer (BookRags, 2006). However, the first dedicated wheelchair (invented four centuries ago and called an invalids chair) was made for Phillip II of Spain (Bellis, 2006). Engineer, Harry Jennings' invention was the earliest wheelchair similar to what is in use today. That chair, built for his paraplegic friend, Herbert Everest. Together they founded Everest and Jennings, a company that monopolized the wheelchair market for many years. An antitrust suit was actually brought against Everest & Jennings by the Department of Justice, who charged the company with rigging wheelchair prices. The case was finally settled out of court (Bellis, 2006). Although the electrically powered wheelchair first appeared around the time of World War I, manually powered wheelchairs remained the norm until the rising number of quadriplegics in the 1960s created sufficient demand for wheelchairs propelled by other means. Electric wheelchairs can now be activated by hand, head movement, tongue, and breath. In 1982, astronomy student Martine Kempf, a native of France, developed a computer program that responded to voice commands--the Katalavox--which is now used to power both wheelchairs and microscopes.

The growing interest in wheelchair sports has benefited from improvements in wheelchair durability and maneuverability. Tom Houston, a pipefitter paralyzed by a fall in 1979, designed the HiRider with the help of fellow pipefitter Ray Metzger. This revolutionary wheelchair, which went on the market in 1989, allows the user to maintain a standing position while moving about. Wheelchairs capable of climbing stairs and curbs also are manufactured now. In 1987, West Germany issued the Rollsteiger, and in 1992 in the United States a high-priced computer-and-sonar-equipped ACCESS Mobility System was offered in 1992. On flat surfaces, both models utilize the standard four wheels, but convert to tank-like treads to climb over obstacles.

The stair-climbing ACCESS chair uses its track mode to adapt to curbs and even misaligned sidewalk slabs. Controlled by an armrest-mounted joystick, ACCESS can maintain a 6 mph pace for 12 miles or ascend and descend staircases as steep as 36 degrees. Also in the early 1990s, the first compact, elevating, powered wheelchair was produced. Called the Mangar Freestyle, it is able to raise its seat using pressurized air like bellows. This allows the user to reach objects above the normal range of ordinary wheelchairs. Many of the newest chairs use the same "ultralight" materials that go into aircraft. For races and wheelchair competition of all sorts, tough stainless steel chairs are designed that offer both speed and endurance (Bellis, 2006)

It is worthy of note that the CAD system is also being used for wheel chair manufacture. Among works involving application of CAD for wheel chair design, DongHan *et al.* (2004) created design guidelines using computer simulation for the development of manual pediatric wheel chair and their results will provide wheelchair and seating manufacturers designing products for pediatric population with insight as to the magnitude and types of forces that can be imposed upon their products in a frontal crash within an automobile. Several other notable researches had also been done on the wheel chair in recent times to ensure safety of users and to modify existing wheel chair designs for comfort of users. Amongst such works is the development of wheelchair capable of easily going on and off sidewalks, riding on grass, sand and other places where no ordinary chair is capable of going by Students and professors from Cal State L.A., along with staff from Ranch Los Amigos Medical Center's Rehabilitation Program in June 1999 (Gallegos, 1999). Armstrong and Buning (2004) studied Wheelchair Users Attitudes, Knowledge, and Behavior When Riding Fixed-Route Transportation with the objectives of discovering the wheelchair transportation accessibility barriers that are unique to fixed route transportation, and determining the relationship between barriers and variables such as type of wheelchair, age of wheelchair user, and size of public transit system that may have an effect on these barriers.

Bertocci *et al*. (2003) studied the effects of wheelchair-seating stiffness and energy absorption on occupant frontal impact kinematics and submarining risk using computer simulations and the study demonstrated the usefulness of computer simulation techniques by systematically assessing the effects of wheelchair-seating design on occupant injury risk. Their findings indicated that seat surface stiffness and energy absorption influence submarining risk in a wheelchair-seated occupant exposed to a frontal crash.

There are different types of wheel chair options available in the market today unlike in the past where patients simply go to a doctor and get a prescription for a manual wheel chair. According to a report posted on 1stSeniorcare (a paraplegic utility chair marketer in the United States) website several types of wheel chair exists. The various types of wheel chair are: The lightweight or sports manual wheel chair, Standard manual wheelchair, Children's or teen manual wheel chairs, Specialty chair, Institutional manual wheel chair, Power Chairs, and others (1stSeniorCare, 2006).

METHODOLOGY

The method of approach used in this study involves the survey and study of existing wheel chair designs which was evaluated and reviewed. Appropriate design was then developed to accommodate all categories of paraplegics based on varying anthropometry sizes. The design was drafted using Autodesk's AutoCAD 2006 to develop the wheel chair model and other output view of the software. Microsoft Access 2003 was used for data management within the software. Access enabled the software to collate the result of any input and then backs up this data for display in the final report or output. CorelDraw 12, a graphical tool was also employed in the course of this project. CorelDraw has capabilities to create lines, colors and objects, both simple and complex. It also assisted in creating the models within this project alongside AutoCAD 2006 modeled into 3-Dimensions. Suitable programming language, Microsoft Visual Basic 6.0, a professional software which arranges the package first as a project and was later created into a projector file with .exe extension which can be run on any computer machine. It was employed to develop the software which is capable of triggering the modification of the wheel chair model to alter its physical dimensions to suitable one for any particular anthropometry size. These Computer programs were used to develop the software for designing wheel chair. The software was therefore developed using a combination of different computer programs mentioned above which forms the materials used for the project. The draft was developed into a clear 3-Dimensional (3-D) model of a wheel chair. This 3-D model created in AutoCAD allowed various views of the wheel chair to be clearly seen including the perspective, plan, side (left and right), bottom and front views. A performance evaluation of the designed CAD system was finally carried out with different anthropometric measurements of paraplegics.

DESIGN DETAILS

The manual wheel chair was chosen for consideration. The design and software development involve: dimensions determination and analysis of component parts, material selection and ergonomics consideration. The design considerations made for the design of various parts of the wheel chair are as described below:

Frame: This was made of light weight materials to enable easier mobility and transportation. Materials considered include; Stainless steel, chrome, aluminum, airplane aluminum, steel tubing, and titanium. Hollow Stainless steel was chosen to enhance its light weight. This design software mainly care for rigid frame chairs, however users may also employ it as a guide in designing the standard cross brace frame.

Upholstery: There are numerous types of upholstery materials for the manual wheel chair. Upholstery for manual wheel chairs must be able to withstand daily use and all kinds of weather. Manufacturers have developed upholstery made of cloth, synthetic fabrics and leather. Synthetic fabrics upholstery was selected to be used for the seat and the backrest. There are also numerous seating options for manual wheel chairs. Since the seating for manual wheelchairs are sold separately the width and depth of the seating were chosen.

Wheel and Casters: There are four wheels needed two larger wheels at the back and two smaller wheels (casters) in the front. Most manual wheel chairs use the 24 inches standard pneumatic tires at the back thus, 60cm large wheels and 20 cm diameter small wheels were used. The position of braking system on the circular handle mounted on the wheel of manual wheel chair has been carefully located for user convenience. Some wheel chair designs also have some stopper attached that user may pull to stop. This feature is more effective especially when user have to stop the wheel chair while moving along a steep slope and this has equally been incorporated into the design.

Footrest and Hand guard: These are made of rubber materials. The foot rest which is expected to conveniently provide a platform for the user's feet and so anthropometric measurements of users' ball of foot width and foot length assisted in designing for the dimension of the foot rest. It should also have good grip to take care of friction and stabilize user's feet. The hand guard which user's assistance will hold while pushing the user will be designed to fit the palm outline for good ergonomics balance as the assistance grasp the handle.

Identification of Design Population

Since the software is expected to design for a wide category of people within the Nigerian paraplegics' population, it is important to obtain anthropometric data of the Nigerian paraplegics.

Traditionally, designers have used limits of 5th % female to 95th % male. This strategy can 'design out' large sections of a user population (Burnett, 2003). Due to this the 5th percentile of female anthropometry to the male percentile of Male anthropometry was obtained from a survey carried out by the author. A study of human anthropometry was carried out to determine the target population for the wheel chair design and also to determine the various parameters of the human anthropometry which are needed for the wheel chair design. These percentile values were used to determine the range of the wheel chair dimensions for the wheel chair. Thus the output models for the parts to be designed could then be developed. Also the necessary design coding needed for decision making by the software was made. The 5th, 50th and 95th percentile of Nigerian male paraplegics of the identified parameters is shown in Table 1.

Dimension Calculations for Various Parts

The Anthropometry of paraplegics for the 50th percentile obtained from the survey of The author as shown in Table 1 was used to calculate dimensions of the wheel chair. Therefore, wheel chair for this category of paraplegics (50th percentile male), will make use of the following dimensions: Seat Length: 33cm, Seat width = 45cm, Backrest length = 30cm, Backrest width = 45cm, Seat to top of backrest=55cm, Seat to Top of backrest = 55cm, Seat to Footrest depth = 45cm, Total height of wheel chair = 125cm. Other dimensions are: Hollow frame Outer diameter (d_0) = 2.4cm, hollow frame inner diameter (d_i) = 1.8cm, Footrest support frame outer diameter (f_0) = 1.3cm, footrest support frame inner diameter (f_i) = 0.9cm, Wheel diameter = 60cm, Caster diameter = 20cm. (Author's Survey).

The volume of the rigid frame was calculated to be 0.54m^3 assuming the total length of the frame to be 522 cm (Author's survey) and the mass of the frame was calculated to be 4.24 kg. The density of steel is 7.85g/cm^3 (Callister and Williams, 2001).

Table1: 5th 50th and 95th Percentile of Anthropometry of Nigerian Male Paraplegics (cm)

Category	5th percentile	50th percentile	95th percentile
Age (years)	8	24	46
Height	118.21	148	163.5
Weight	20	45	56.2
Sitting height	57.45	69.5	78.875
Forward reach	61.225	75	90
Maximum body width	29	40	55
Eye height sitting	49.45	63	70
Mid shoulder height	41.45	52.25	60
Buttock to popliteal	29.725	37.5	44
Buttock to knee length	36	44.25	54
Popliteal height (sitting)	31	41	50.11
Knee height (sitting)	37	50.5	62.1
Thigh clearance (sitting)	8	9	12
Elbow to fingertip	36.225	44	51.775
Chest circumference	62.225	82	101.3
Shoulder circumference	71.45	96.5	118.375
Hip (buttock) circumference	56.15	75	87.7
Head breadth	15	17	21
Head circumference	51	55	63.695
Inter pupilliary breadth	7	8.75	10.775
Waist circumference	57	69.1	85.55
Waist depth	16	20	24.1
Buttocks to heel length	67.45	94.5	106.55
Shoulder breadth	31	36.5	45.1
Hip breadth	20.45	27.5	32
Forearm to forearm breadth	32	40	49
Head height	19	22	27
Head length	20	24	28
Eye to top of head length	7	10	14.055
Chin to eye height	11	13	15
Neck circumference	27	34	41.55
Hand length	14	18	23.55
Hand breadth at metacarpal	6	10	11
Hand breadth at thumb	8	12	14
Hand thickness at metacarpal	2	3	4
Foot length	16	22	25.06
Ball of foot width	6	10	12.955
MUAC	17	22.8	34.275
Abdominal girth	53	65.05	85.1
Mid-thigh circumference	21	29	40.6

***Source**: Author Survey*

Table 2: Dimensions Used for the Design

Anthropometry Parameters	50th percentile Male Anthropometry	Corresponding wheel Chair dimension
Buttock to popliteal	37.5	Seat Length
Hip Breadth (Seating)	27.5	Seat Width
Mid-Shoulder Height	52.25	Seat to Top of back-rest
Maximum body width	40	Backrest width
Foot Length	22	Footrest length
Ball of foot width	10	Footrest width
Popliteal height (sitting)	41	Seat to Footrest depth

The footrest frame was designed to hold the footrest pad in place. It has a long rod to fit to the rigid frame securely. It is made of hollow steel (cylindrical) of inner diameter = 0.9cm and outer diameter=1.3cm.

The wheels are to be seated on bearings for easy movement when chair is being driven by the user manually. The caster is required for turning and is also mounted on bearing supports. The diameter of the wheel and casters are 60cm and 20cm respectively.

The seat frame was made of light aluminum plate of thickness 2mm. This is subject to the users' anthropometric parameter. The plate was supported beneath with thin rods bolted to the rigid frame. The metal plate was padded with foam and covered with leather which enables a good support for the users. The back rest whose dimension (height and width) depends on the users anthropometry was made of fabric. Leather could be used depending on user or manufacturer choice. The back rest was screwed to the rigid frame.

Wheel Chair Balance

The balancing of the wheel chair was considered. It is built on a rigid support, therefore it is balanced on all sides and it is enhanced by its four wheels (caster inclusive) which are on the same baseline. The user's weight will be distributed on the whole chair to further enhance its balance. Figures 3 a-d show the model of the wheel chair showing various views.

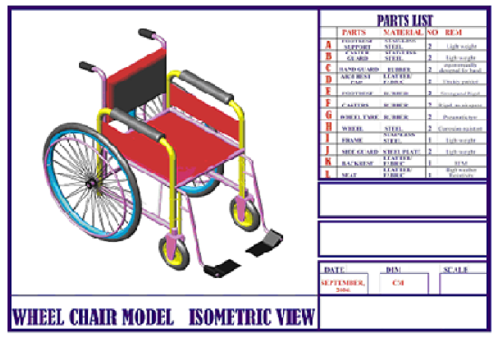

Fig. 3.4a: Isometric View of the Wheel Chair Model

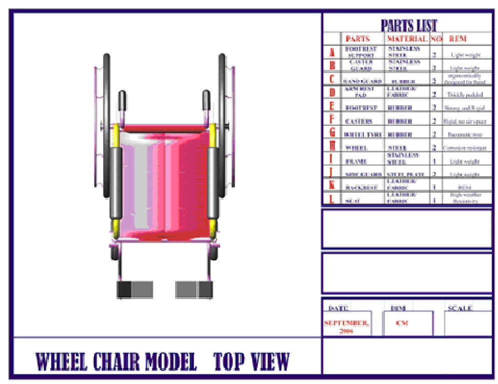

Fig. 3.4b: Plan View of the Wheel Chair Model

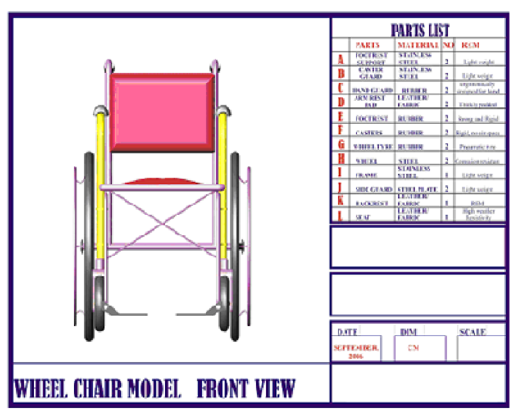

Fig. 3.4c: Front View of the Wheel Chair Model

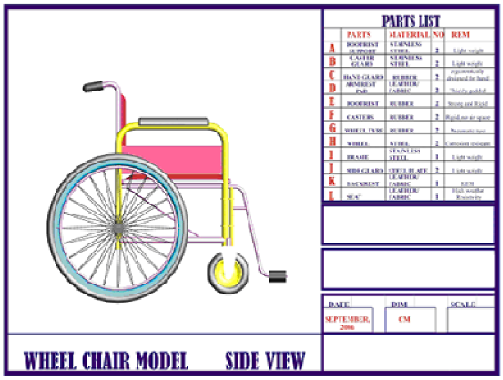

Fig. 3.4d: Side View of the Wheel Chair Model

Decision Variables Used within the Software

These decision variables are the instructions fed to the program to determine the appropriate dimensions for the wheel chair parts based on users anthropometric data input. The width of the Backrest was determined by the target users' maximum body width. From the survey, the maximum body width of target users falls within the range of 27cm to 55cm. This was used to instruct the software to allow a +2 to 5cm allowance for the wheel chair back rest width. The Seat Length was determined by the users' buttock to popliteal length. A range of 29 to 45 based on the anthropometric analysis was used to program the software to allow a -2 to -5cm allowance in the seat length. The Seat width was programmed to be equal to the back rest width as it permits the users' whole body to fit into it. The Seat to Top of Back rest was determined by the user's mid-shoulder height which falls within a range of 42 to 60cm. This was used to instruct the software to enable allow a +2 to +5cm allowance for the wheel chair seat to top of backrest height. The Length of footrest was determined by the users' Foot length which falls within a range of 15 to 26cm. This was used to instruct the software to enable allow a +2 to +5cm allowance for the wheel chair seat to top of backrest height. The Breadth of footrest was determined by the users' ball of foot width which falls within a range of 6 to 13cm. This was used to instruct the software to enable allow a +2 to +5cm allowance for the wheel chair seat to top of backrest height. The Vertical height of Footrest from seat was determined by the users' popliteal height (sitting) which falls within a range of 30 to 50cm. This was used to instruct the software to enable allow a +2 to +5cm allowance for the wheel chair seat to top of backrest height.

Development of the Software Using Visual basic 6.0

The final software development was packaged using Microsoft Visual basic 6.0. The various graphics tools presents in the Visual basic program was used to design the software interface while program coding in the Visual Basic language was used to package the decision variables to enable the software analyses its inputs and process accordingly. The output interface was then designed to accommodate view options of the wheel chair model, parts designed, whole and parts dimensions. This software was also provided with a print option for users to print the final output.

RESULTS AND DISCUSSION

The CAD for Wheel chair development was developed with various interactive features. The final package was produced on a Compact Disc Recordable (CD-R) and branded as Wheel Chair Designer.

The wheel chair designer software can run on most system even low capacity ones. However, for optimum performance, a minimum configuration of Pentium-1, 233- MHz is required with a minimum of 15MB free space on the hard disk installed and 32MB RAM or higher. Other requirements include CD-ROM Drive and a Printer to print the final output.

For installation, **t**he CAD software stored on CD -R upon insertion into a machine will auto run itself on any Windows operating system without the user having to run it.

To use the software, double click **wheel chair designer** when it runs, its first display introduces the user to the package and its intended use. Users have an option to quit or continuing exploring the software by clicking Next. This display can be seen in Figure 4.1.

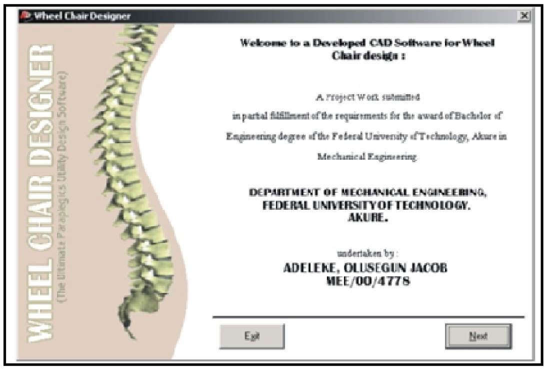

Fig. 4.1: The Introductory Display of the Software

The next display instructs the user to input all required anthropometric data for the wheel chair design. The display is as seen in Figure 4.2.

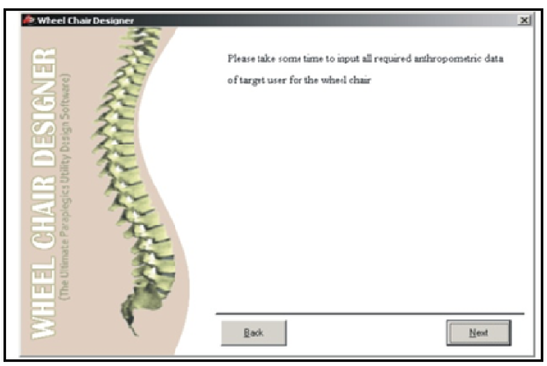

Fig. 4.2: The Instructional Display of the Software

Next is a screen showing the required parameters the user is expected to input into the software. This section permits the user to enter variables in centimeters, millimeters or metres. However, final result will be displayed in centimeters which is also the default unit of measurement. See Figure 4.3.

Whenever the user clicks next, the program validates to ensure that no field is left empty and also ensure that only numeric values are input into the program. On validation success, the next display in Figure 4.4 comes on. A progress bar showing the processing of the input to display the result of the design process is seen. This bar shows the progress of the software as it reads the input, analyse them to determine appropriate wheel chair dimensions based on the decision variables already programmed into the software. The finish Tab (bottom right on Figure 4.4 is inactive until the progress bar reaches completion.

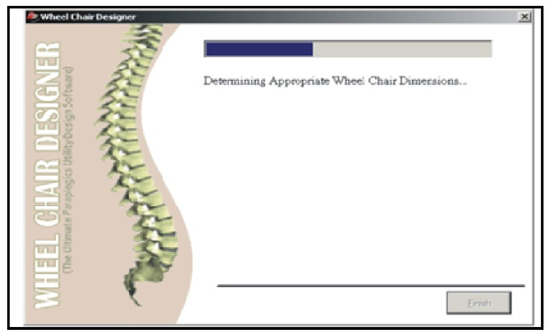

Fig. 4.4: The Process Progress Display of the Software

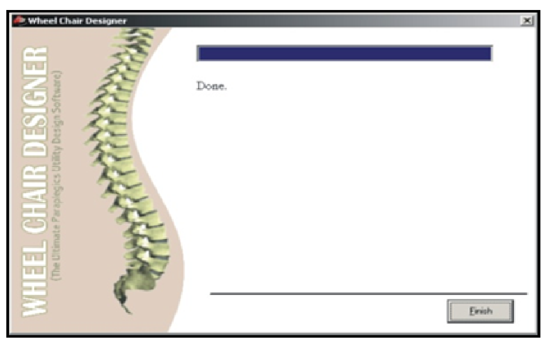

Fig. 4.5: Display Showing Final Processing of the Input Data

On completion of the data processing, the Finish tab becomes active just as the progress bar reaches completion. On clicking of the Finish Tab, the output is displayed. The displayed output shows the various dimensions of the wheel chair designed for the intended user(s). The output display also gives user the option of viewing the parts dimensions in isolation and also the part images in isolation. Also there is a print option which allows the user to select printer and other print settings based on the configuration of the printer installed.

Figure 4.6: The Output Selection Page

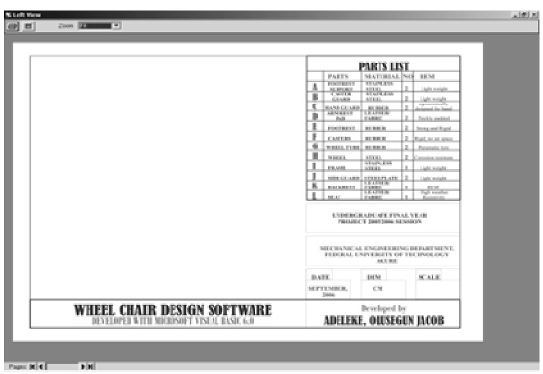

Fig. 4.7: The Output Layout for Display of Wheel Chair, Dimensions and Parts

PERFORMANCE EVALUATION OF WHEEL CHAIR DESIGNER

A test of this software was carried out for the design of wheel chair for the 50th percentile male paraplegics in Nigeria using data the author's survey. This data was entered into the parameter input display of the software. The output of the software reveal different views and parts of the wheel chair designed for the user whose anthropometry was entered into it. The user will click any/or all of the checkbox of the output selection page shown in Figure 4.6 to display the view he prefers to see or print. Figures 4.9 to 4.18 shows various displays which the user may view or print for the data entered therein. The dimensions shown in the view are the sizes of the sides and parts of the wheel chair suitable for this user. There is a print icon at the top left corner of Figures 4.9 to 4.18 which allows the user to print the view.

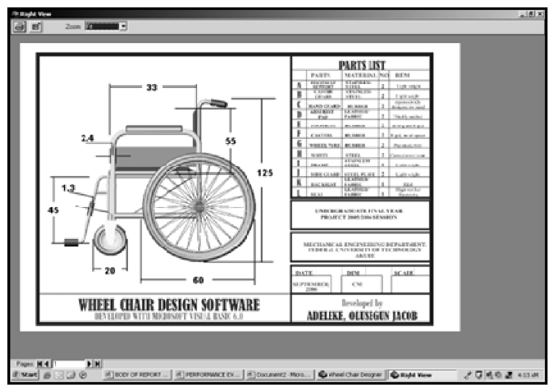

Fig. 4.9: Right Side View of the Wheel Chair

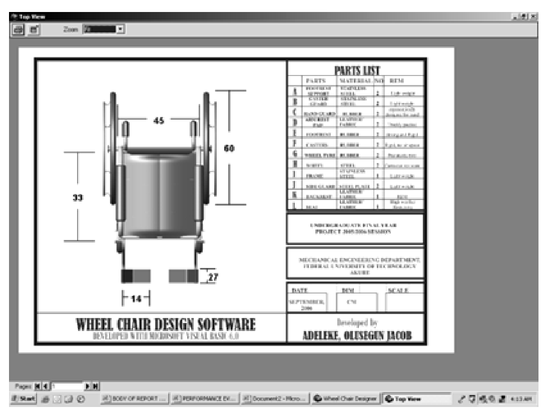

Fig. 4.10: Top View of the Wheel Chair

The summary view of the wheel chair for the data entered for this person is as shown in the Table 4.4.

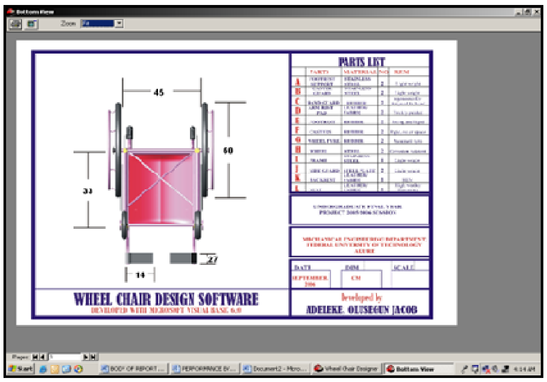

Fig. 4.11: Bottom View of the Wheel Chair

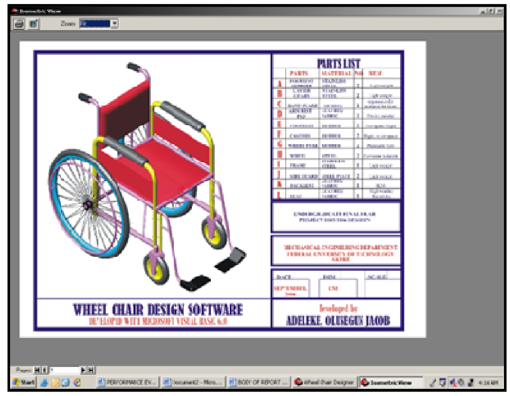

Fig. 4.14: Isometric View of the Wheel Chair

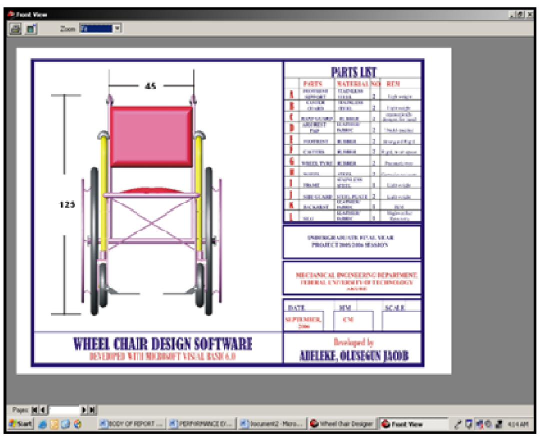

Fig. 4.12: Front View of the Wheel Chair

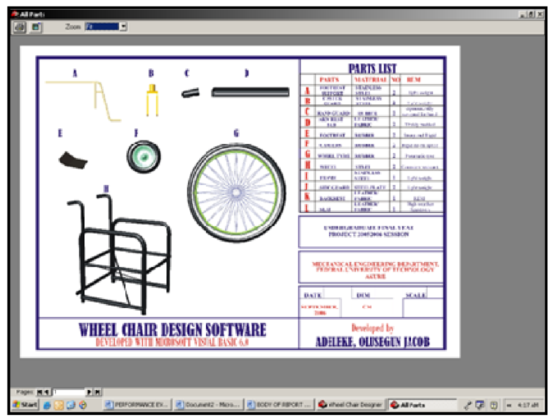

Fig. 4.15: View Showing The Parts of the Wheel Chair

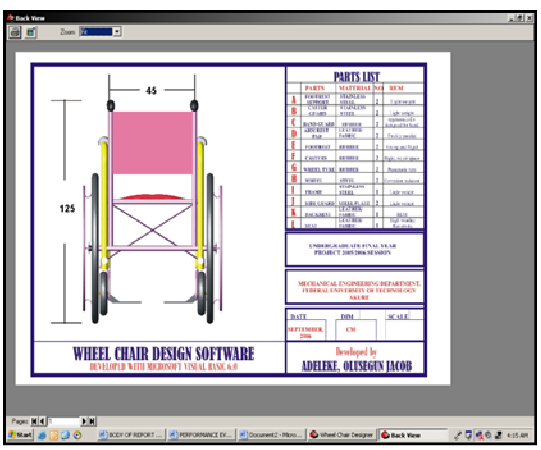

Fig. 4.13: Back View of the Wheel Chair

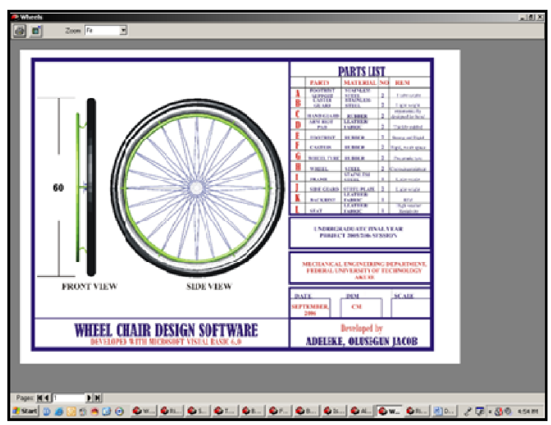

Fig. 4.16: Wheel and Tyre of The Wheel Chair

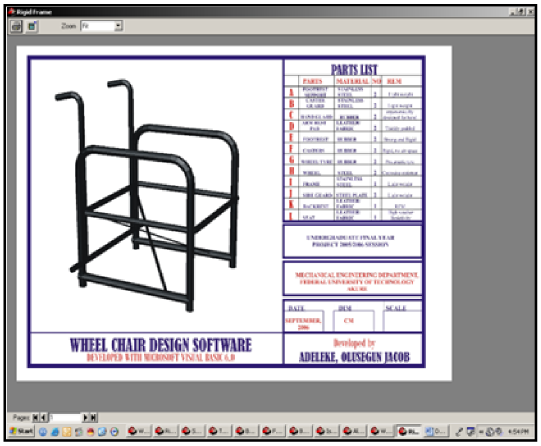

Fig. 4.17: Rigid Frame of The Wheel Chair

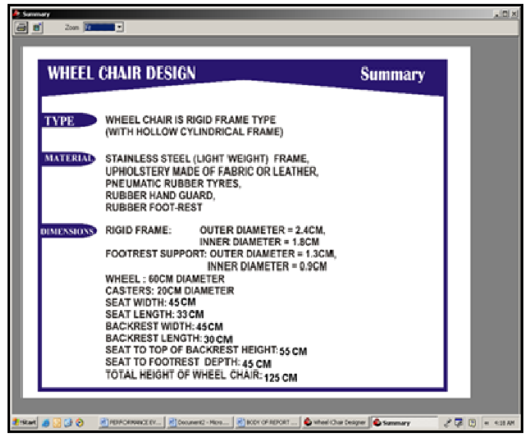

Fig. 4.18: Summary of the Wheel Chair Dimension Specification

Table 4.4: Table Showing Summary of Evaluation Test Result of Wheel Chair Designer

Part	Description	Dimension
Wheel Chair	Rigid frame type	Total height =125cm
Rigid Frame	Hollow frame of Stainless steel material	
Upholstery	Fabric or leather	Large enough to cover seat and backrest
Hand guard	Ergonomically designed to fit human palm	Inner diameter of 2.4cm
Footrest	Rubber material designed to accommodate users feet	Width = 14cm Length = 27cm
Seat	Dimensioned based on user's anthropometry	Width = 45cm Length = 33cm
Backrest	Dimensioned based on user's anthropometry	Width = 45cm Length = 30cm
Footrest support frame	Used to support footrest	Vertical height = 45cm Diameter = 1.3cm
Wheel	Pneumatic rubber tyres on steel frame	Diameter = 60cm
Caster	Rigid rubber tyre on solid steel frame	Diameter = 60cm

***Source**: Wheel Chair Designer Software Test Result*

The performance evaluation test conducted for 50th percentile male paraplegics data obtained from the author's survey showed how the software can be used for wheel chair design. For wheel chair required to be customized for a particular user, all that will be required will be the anthropometry of the user.

CONCLUSION

A software package has been successfully developed, branded and packaged on a Compact Disc recordable CD and installable on a windows platform. This software will allow manufacturers to easily design wheel chair for the Nigerian paraplegics' population, having successfully taken into consideration the anthropometric data of this category of people. Also, a lot of features have been incorporated into the software to allow for good user friendliness and interactivity which is a major feature of modern software.

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