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ORIGINAL RESEARCH ARTICLE

ERGONOMIC ANALYSIS OF A DEVELOPED WHEELCHAIR USING CREATIVE ALGORITHM

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ABSTRACT

Mobility aids are important for disabled and aged patients for transportation or replacement for walking especially in indoor and outdoor environments. To guaranty the effective and efficient use of these mobility aids devoid of any form of epidemiological conditions, the level of comfort and ease of use must be ascertained. In this research, a simple and affordable wheel chair designed in previous work was analyzed to support patients in terms of ease and comfort of use. The method adopted for this study was the use of creative algorithm. Anthropometric measures were considered in the dimensioning of the wheel chair seat. It was necessary to test how ergonomically comfortable the wheelchair was in use by deploying an effective decision metrics tool known for dealing with complex decision-making process and may aid the decision maker to set priorities and make the best decision. By reducing complex decisions to a series of pair wise comparisons, and then synthesizing the results. Our findings showed an average ergonomic rating of 0.62 which indicate a relatively high degree of comfort ability in the use of the wheelchair. The use of these wheelchairs would greatly improve the community of people who have lost some means of independent mobility thereby leading to an improvement in their self-esteem. This will enable them pursues their daily vocation and life goals. The wheel chair will also serve as a novel for medical facilities in hospitals and help facilitate movement of disabled patients in homes, schools, entrepreneurial centres and hospitals.

1.0 Introduction

The recent developments of science and technology has drastically changed the way a normal person lives his/her life, modern technology has made it possible for the discovery of many functional area of life. For instance, transportation, business transactions and education has been made easy. Technology has really made our lives better also made our lives easier, faster, better and more fun, but there are certain categories of people who have not been able to fully benefit from this development, on particular disabled people with limited mobility are still living a miserable life. Rohit et al. (2013). This stem from their inability to access basic skill acquisition centres arising from the shortage of infrastructural facilities needful for accessibility and mobility requirements. This turns most paraplegics into unemployable people, thereby they tend to end up as beggars along major road and markets places under awful circumstances reducing the quality of life of these set of people which invariably drops the nation gross domestic product (GDP) which is a critical economic index for measuring the strength of any nation (Ashiedu and Igboanugo, 2013).

Independent mobility is without doubt essential to individuals of any age as children without safe and independent mobility are denied beneficial learning opportunities, which places them at a disadvantage when compared with their peers. Adults are also not left out as those who lack an independent means of locomotion are less self-sufficient, which can lead to a negative self-image and depression. A lack of independent mobility at any age, places additional obstacles in the pursuit of vocational and educational goals Richard et al. (2004)

A wheel chair aims to provide aid to those physically challenged and aged persons by providing them with some sort of mobility which would greatly improve their living. A wheelchair is a type of chair usually used by disabled people. It is moved either manually (by pushing the wheels with the hands, or pushed from behind with handles by somebody who is not sitting in the wheelchair) or by automated systems such as electric motors which can be controlled by the wheelchair user (the person sitting in the chair) or by somebody walking behind or beside the wheelchair if the wheelchair user needs help to move their wheelchair.

Wheelchairs are used by people for whom walking is difficult or impossible due to illness, injury, or disability. It comes in a wide variety of formats to meet the specific needs of their users. They may include specialized seating adoptions, individualized controls, and may be specific to activities, as seen with sports wheelchairs and beach wheelchairs. The most widely recognized distinction is between powered wheelchairs ("power chairs"), where propulsion is provided by batteries and electric motors, and manually propelled wheelchairs, where the propulsive force is provided either by the wheelchair user/occupant pushing the wheelchair by hand ("self-propelled"), or by an attendant pushing from the rear. Wheel chair as a support device can ease the lives of many disabled people, particularly those with severe impairments by increasing their range of mobility (Nipanikar et al., 2013). This research centres on design, development and analysis of a wheelchair for disabled (physically challenged) individuals and aged people to help facilitate a large amount of independence for those who can neither walk nor operate a mechanical wheelchair alone as it requires great effort and help of other people. The first wheelchairs were self-powered, and worked by a patient turning the wheels of their chair manually (Mohan et al., 2012), Bellis, 2018)). Generally, wheel chair system find variety of applications which includes but not limited to; hospitals assisted homes and sports. Wheel chairs can also be adopted during emergency situation like road accidents, fire accidents, air accidents, maternity emergency and physical disorders.

1.1 Several Works Done on Manual Wheelchair

Nikhil et al. (2017) designed and fabricated a lever propelled wheelchair. The paper was of the opinion that many people who are disabled due to some injuries or other chronic diseases may not be able to wheel a conventional wheelchair. In their design they adopted a lever for transmitting the force to move the wheel chair instead of applying the force on the push rim. The wheelchair was designed in such a way that it requires less efforts and it is cheaper than the other advanced wheelchairs. Pezzuti et al. (2006) suggested that during the last decades sport activities for disabled people are practiced by many athletes, both amateurs and professionals.

They designed a chair with a self-adjustable cushion in order to give the possibility of playing safely. Many factors were taken into account such as athletic performance, safety of player and opponents, comfort and reliability. In their article that employed the application of CAD-Multibody techniques to optimize the wheelchair for basketball. The target of their investigation was to give athletes the possibility of performing quick forward accelerations without rollover tendencies.

Ebrahimi et al. (2016) was of the opinion that biomechanical aspects of wheelchair design play an important role in physical activity and social participation of disabled individuals. In their article they reviewed key biomechanical features of wheeled mobility devices including propulsion methods, overuse injuries, assistive technologies, prevention of pressure ulcers, and tire and frame design.

Khaled (2016) proposed the design and development of a reconfigurable wheelchair for rehabilitation and self-assistance to fit the size of a seven years old child (average 35 kg weight). Though the proposed prototype was developed to fit a child, it can be resized, after considering variations in weight and size, to fit an older adult. Their design has a mechanism that enables the user to transform from sit-to-stand (STS) posture and vice versa. With the help of the developed wheelchair, the user would also be able to adjust the posture of his upper body using an adjustable back support. This configuration would allow the user to use the wheelchair as a mobility device as well as for rehabilitation purposes without the need of external support. The availability of STS and back adjustment mechanisms would allow the user to do regular exercising which would enhance blood circulation as sitting for long periods inflates lower limbs disability. The proposed configuration would help in enhancing the functional capabilities of end-users allowing for increased independence and ultimately quality of life. Other interesting research done on electrical wheel chair to support movement of disabled people include Cooper (1998); Razak and Shehab (2013); Nida and Riaz (2014); Swapna et al. (2016); Rakshith et al. (2017) and Alexander et al. (2016).

2. Materials and Method

2.1 Design Process

The seat was designed ergonomically, considering all the required anthropometric measurements. Parameters considered along with their measures are as shown in Table 1.

Table 1: Anthropometric data (Ashiedu & Igboanugo, 2013)

S/N	Parameters	Brief description	Dimensions (mm)
1	Sitting height	Distance between the buttock and top of the head in sitting	936
2	Popliteal height	Distance between the underside of the foot to the underside of the thigh at the knees in seating position	469
3	Knee height (sitting)	Distance between the sole of the foot to the anterior surface of the thigh with the angle and knee each flexed to 90°	579
4	Buttock to knee length	Distance between the buttock and knee	590
5	Hand length	Distance between the wrist and the top of middle finger.	220
6	Arm rest height	Distance between the underside of the	

		thigh to the underside of the arm	
7	Hip breath	Maximum horizontal distance across the hips in the sitting position	439
8	Shoulder breath	Maximum horizontal breath across the shoulders, measured to the protrusions of the deltoid muscles.	480
9	Elbow to wrist length	Distance between the elbow and wrist	
10	Angle of back	Inclination angle between the seat and back rest	110°

2.2 Evaluation Metrics

The parameters that were taken into consideration in the design stage were also observed during analysis stage for evaluating the total performance indicators of the system. The metrics considered in the design and fabrication of a smart wheel chair includes: Goal and objective, Time efficiency, Path navigation, Precision, and Strength/Energy efficiency.

The weighted value shows the order in which each metrics is important to the design. The weighted values of each metrics were obtained through a process known as analytical hierarchical process (AHP).

Figure 1 Developed Wheelchair

2.3 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is one of multi criteria decision making method that was originally developed by Prof Thomas Saaty in 1980. It is known as an effective tool for dealing with complex decision making and may aid the decision maker to set priorities and make the best decisions. By reducing complex decisions to a series of pair wise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision-making process. The qualitative assessment of the ergonomic factor (ER) is provided below.

If ER is between 0.10 – 0.29, then the wheelchair is very uncomfortable

If ER is between 0.30 – 0.49, then the wheelchair is slightest uncomfortable

If ER is between 0.50 – 0.65, then the wheelchair is comfortable

If ER is between 0.66 – 0.78, then the wheelchair is slightest comfortable

If ER is between 0.80 – 1.00 , then the wheelchair is very comfortable

The standard verbal judgement scale generally accepted for use in the AHP subjective and objective is presented in table 2.

Table 2: A Pair wise Comparison Criteria

S/N	Verbal Judgement	Numeric value
1	Extremely important	9
2	Very important	7
3	Moderately important	5
4	Moderately less important	3
5	Equally important	1

2.4 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is one of multi criteria decision making method that was originally developed by Prof Thomas Saaty in 1980. It is known as an effective tool for dealing with complex decision making and may aid the decision maker to set priorities and make the best decision. By reducing complex decisions to a series of pair wise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision.

In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision-making process.

2.5 AHP Algorithm

The AHP considers a set of evaluation criteria, and a set of alternative options among which the best decision is to be made. It is noteworthy that, since some of the criteria could be contrasting, it is not true in general that the best option is the one which optimizes each single criterion, rather the one which achieves the most suitable trade-off among the different criteria (Saaty, 1980) . The AHP generates a weight for each evaluation criterion according to the decision maker's pair wise comparisons of the criteria. The higher the weight, the more important the corresponding criterion. Next, for a fixed criterion, the AHP assigns a score to each option according to the decision maker's pair wise comparisons of the options based on that criterion. The higher the score, the better the performance of the option with respect to the considered criterion (Saaty, 1980) . In this analysis, the weight gotten through the AHP process is used to develop the intelligence of the system. To obtain the weighted value of each metrics using the analytic hierarchy process the following steps were followed: Develop a model for the decision: Break down the decision into a hierarchy of goals and criteria; derive priorities (weights) for the criteria: The importance of criteria are compared pair wise with respect to the desired goal to derive their weights; check the consistency of judgments; that is, a review of the judgments is done in order to ensure a reasonable level of consistency in terms of proportionality and transitivity. The model architecture is shown in Figure 2.

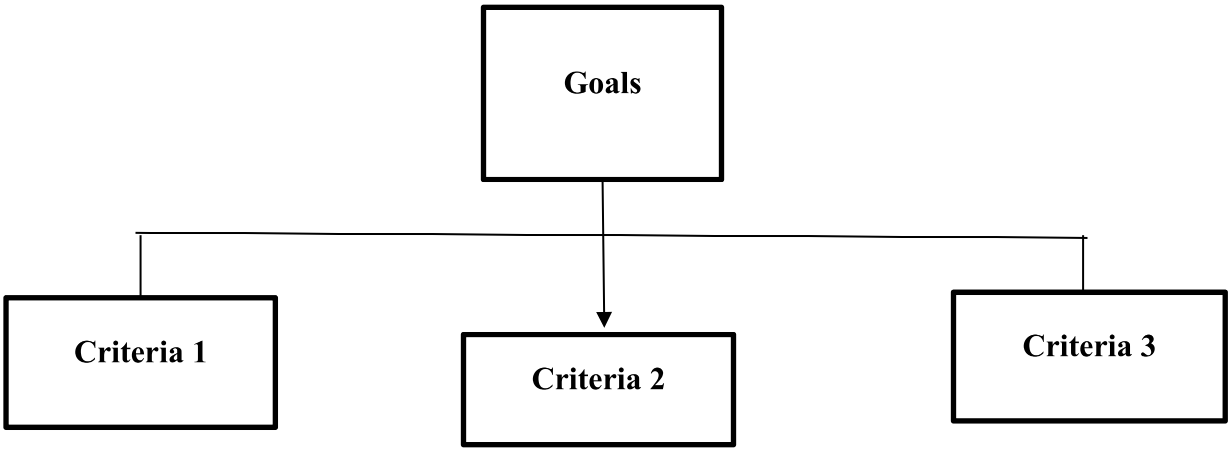

Figure 2: Block diagram of AHP model

2.5 Deriving Priorities (Weights) For the Criteria

This step involves the derivation of the relative priorities (weight) for the criteria. It is referred to as relative because they are measured with respect to each other. The pair wise comparison criteria are presented in Table 3 for ease of reference.

Table 3: A Pair wise Comparison Criteria

S/N	Verbal Judgement	Numeric value
1	Extremely important	9
2	Very important	7
3	Moderately important	5
4	Moderately less important	3
5	Equally important	1

2.6 Ergonomic Evaluation of the Wheelchair

Ergonomics in this context is the process of designing the wheelchair so that it fits the people who use it. It is a branch of science that aims to learn about human abilities and limitations, and then apply this learning to improve people's interaction with products systems and environment (Dohrmann Consulting, 2014). In evaluating ergonomics and comfort, Kapica and Grbac, (1998) suggested that the basic principle of a comfortable seat is contained in the system where the sitting bones take the body weight off, while the feet are not loaded and the spine maintains its natural posture. Construction of upholstery, shape and hardness of the sitting surface, degree of the seat and backrest deformity, etc. along with the product's overall construction determine the sitting comfort and level of tiring (Kapica & Grbac, 1998). The following objectives were considered in evaluating how ergonomically balanced the smart wheelchair developed in Figures 1 and 2 include: Back rest, seat, arm rest, leg rest.

2.7 Analytic Hierarchy Process

Analytic hierarchy process was employed is used to obtain the weighted value of each objective.

Table 3: A Pair wise Comparison Criteria

S/N	Verbal Judgement	Numeric value
1	Extremely important	5
2	Very strongly more important	4
3	Strongly more important	3
4	Moderately less important	2
5	Equally important	1

Taking four (4) objectives stated above, we then have a 4 by 4 matrix. The diagonal elements of the matrix are always 1, we then proceed to fill the lower triangular matrix and upper triangular matrix.

Table 4: 4X4 Criteria Matrix

	Back rest	Seat	Arm rest	Leg rest
Back rest	1	0.5	0.25	0.33
Seat	2	1	0.2	0.5
Arm rest	4	5	1	2
Leg rest	3	2	0.5	1
Sum	10	8.5	1.95	3.83

If bij is the element of row i and j of the matrix, the upper diagonal matrix is the reciprocal of the value filled in the lower triangular matrix. It's given by the formula

$$b_{ij} = \frac{1}{\mathrm{bij}} \qquad (2)$$

2.8 Normalized Matrix (B_{norm})

Normalizing the matrix means to divide each element in every column by the sum of that column. This is given by the formula:

$$\overline{b}ij = \frac{\mathrm{bij}}{\sum_{n=1}^{m} \mathrm{bij}} \qquad (3)$$

Table 5 shows the normalized criteria comparison matrix

Table 5: Normalized Criteria Comparison Matrix

	Back rest	Seat	Arm rest	Leg rest
Back rest	0.1	0.06	0.13	0.09
Seat	0.2	0.12	0.10	0.13
Arm rest	0.4	0.59	0.51	0.52
Leg rest	0.3	0.24	0.26	0.26

The criteria weight vector w (that is a m-dimensional column vector) is built by averaging the entries on each row of Anorm. It is given by

$$w_j = \frac{\sum_{i=1}^{m} \bar{a}_{lk}}{m} \qquad (4)$$

Table 6: Criteria Weight Matrix

Back rest	**0.09**
Seat	0.14
Arm rest	0.51
Leg rest	0.26

2.9 Checking for Consistency

The procedure in checking for consistency

Determine a weight sum vector, Ws

$$\{WS\} = [C]\ \{W\} \tag{5}$$

Weight Sum Vector Matrix obtained [0.38, 0.56, 2.09, 1.07]. To find the consistency vector,

$$\{Consis\} = \{WS\}\{\frac{1}{W}\} \tag{6}$$

Consistency Vector Matrix

4.03
4.05
4.14
4.07

Average of the elements of {Consis}, is denoted as λ

$$\lambda = \frac{4.03+4.05+4.14+4.07}{4} = 4.07 \tag{6}$$

Determine the consistency index, CI

$$CI = \frac{(\lambda - n)}{(n-1)} \tag{7}$$

Where n is the number of criteria.

$$CI = \frac{(4.07-4)}{(4-1)} = 0.023 \tag{8}$$

Determine the Consistency Ratio, CR

$$CR = \frac{CI}{RI} \tag{9}$$

If CR < 0.10, the rankings are consistent

If CR ≥ 0.10, the comparisons should be recalculated.

Consistency index, RI (n=4) = 0.95, (Saaty, 1980)

$$CR = \frac{0.023}{0.95} = 0.024 \tag{10}$$

Therefore, the ranking is consistent.

Three (3) persons were required to sit on the wheelchair for five (5) hours and were asked to rate the wheelchair based on their perceived level of comfort or distress.

2.10 Mathematical Model for Evaluating Ergonomic Rating

$$ER = \sum_{i=1}^{n} W_i\, M_i \tag{11}$$

Where;

ER = Ergonomic rating

M_i = metrics $\qquad$ W_i = weight of the metrics

$$\sum_{i=1}^{n} W_i M_i \leq 1 \qquad (12)$$

Qualitative assessment of the ergonomics factor (ER)

If ER is between 0.10 – 0.29, then the wheelchair is very uncomfortable

If ER is between 0.30 – 0.49, then the wheelchair is slightest uncomfortable

If ER is between 0.50 – 0.65, then the wheelchair is comfortable

If ER is between 0.66 – 0.78, then the wheelchair is slightest comfortable

If ER is between 0.80 – 1.00, then the wheelchair is very comfortable

Table 7: Verbal Judgement Scale

S/N	Description	Numeric value
1	I feel completely relaxed	0.8-1.0
2	I feel quite comfortable	0.6-0.79
3	I feel uncomfortable	0.4-0.59
4	I feel restless	0.2-0.39
7	I feel pain	0.1-0.19

Table 8: Performance Evaluation

From equation (16)

S/N	Objective criteria	1ST Person	2ND Person	3RD Person
1	Back rest	0.8	0.9	0.86
2	Seat	0.95	0.8	0.8
3	Arm rest	0.5	0.45	0.5
4	Leg rest	0.62	0.7	0.76

Expanding equation 11 further,

$$ER = W_{BR}M_{BR} + W_S M_S + W_{AR}M_{AR} + W_{LG}M_{LG} \qquad (12)$$

By further substitution, 1st ER = 0.62, 2nd ER =0.60 and 3rd ER = 0.64.

Average ER = 0.62

The ergonomic rating score for the overall system after evaluation is completed by three individuals gives a score of 0.62. This shows that the wheelchair is comfortable.

3.0 Results and discussion

The ergonomic rating of the developed smart wheel chair has been evaluated successfully using the AHP process. Each criterion such as the back rest, arm rest, leg rest and hand rest were calculated, and the appropriate weight was assigned. The weight obtained was used for ergonomic assessment of the wheel chair using the mathematical model developed (eq. 1-12) and the information available in Tables 1 to 7. The AHP process was applied to obtain the weight of each performance objectives such as the back rest, arm rest, leg rest and hand rest of the smart wheel. The pair wise comparison criteria are the verbal judgement and numerical values when comparing the performance objectives framework of the design. The four (4) performance objectives were compared which forms a 4x4 matrix as shown in Table 4, their relative importance based on the pair wise comparison criteria were used to the level of comfort experienced. For example, if we consider arm rest very strongly more important than back rest, the arm rest-back rest comparison cell will contain a value of 4. Mathematically, this means that the ratio of the importance of arm rest versus the importance of back rest is 4 (arm rest/back rest = 4). The opposite comparison, the importance of back rest relative to the importance of arm rest, will yield the reciprocal of this value (back rest/arm rest = 1/4) as shown in the back rest-arm rest cell in the comparison matrix.

The importance of a criterion when compared with itself; for example, seat versus seat, and leg rest versus leg rest, or back rest versus back rest; the input value is 1 which corresponds to the intensity of equal importance in the scale of values. This is instinctively sound because the ratio of the importance of a given criterion with respect to the importance of itself will always be equal. The normalized matrix is then obtainedby adding the value in each column and dividing each cell by the total of the column. From this normalized matrix, the criteria weight is obtained by simply calculating the average value of each row.

Next the consistency is checked, when many pair wise comparisons are performed, some inconsistencies may typically arise. The process of checking consistency is shown in section 2.9. For example, considering three criteria such as seat, leg rest and arm rest respectively. If it is observed after evaluation that the first criterion is moderately less important than the second criterion, while the second criterion is strongly more important than the third criterion. An evident inconsistency arises if it was computed in error the decision maker evaluates by mistake that the third criterion is equally or more important than the first criterion. The AHP incorporates an effective technique for checking the consistency of the evaluations made by the decision maker when building each of the pair wise comparison matrices involved in the process. As presented in section 2.9, the procedure for checking the consistency of the results is to first determine the weight sum vector W_s, this is clearly demonstrated in equations 5 and 6. The consistency ration of 0.024 obtained shows that the ranking is consistent. Finally, the ergonomic rating of the wheelchair was calculated which showed that the developed smart wheel chair is quite comfortable.

4.0 Conclusion

The development of a wheelchair has been presented. The research was targeted to offer assistance to disabled and aged persons for easy routing about their various activities. the materials for the construction are local indigenous lightweight materials for the structural members of the supporting frame. The system is economical light efficient. The AHP model, an effective decision metrics technique for complex stochastic process was achieved by reducing complex decisions to a series of pair wise comparisons. The ergonomic rating of 62% showed that the developed wheelchair is quite comfortable for users.It would greatly improve the community of people who have lost some means of independent mobility thereby leading to an improvement in their self-esteem. Thus, enabling them pursue their vocational and educational goals. In conclusion, creative algorithm like Fuzzy logic and ANFIS can be adopted in subsequent research.

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