



Assistive Product Design for Children with Cerebral Palsy and Mobility Impairments: Adopting User-Centered Design Approach

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Abstract

Cerebral palsy (CP) is a major cause of physical disability in children, significantly affecting their mobility. Although the global prevalence of CP has declined, a substantial number of children across various regions still experience its challenges. Assistive technology (AT) plays a crucial role in enhancing their quality of life. However, current AT solutions often fail to address the diverse needs of children with CP and their caregivers effectively. This study introduces an artificial intelligence (AI)-powered modular wheelchair designed to improve adaptability, usability, and safety for children with CP. The proposed framework integrates multi-modal interfaces and a real-time feedback mechanism. A user-centered design (UCD) approach is employed to identify critical factors for developing innovative powered wheelchairs (PW) tailored to children with movement disorders. Data collected from the Klan Valley region of Malaysia serves as a case study for validation. Findings reveal that children with CP frequently face congenital issues, varying levels of dependence, multiple related conditions, and lower participation in daily activities. Based on these insights, an advanced powered wheelchair is developed to enhance mobility and independence. This research contributes new perspectives and practical frameworks for AT design, supporting future innovations in assistive mobility solutions for children with CP.

Keywords: Cerebral palsy; Assistive technology; User-centered design; Mobility impairments; Powered wheelchairs.

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1. Introduction

Presently, cerebral palsy (CP) is the most typical chronic disability in childhood which encompass a movement disorder group that appear typically at an early stage. An underlying reason is the injury to developing brain, which occurs among prenatal to neonatal stages.^[1] The signs and symptoms of CP vary among individuals greatly and might alter over the time.^[2] In several aspects, CP will be characterized by heterogeneity which includes underlying cause, risk factors, functional limitation severity, clinical features, secondary conditions associated with treatment options and condition progression throughout the life of an individual.^[3,4] A major cause of this is varied and intricate thus leading to the broad spectrum of symptoms and varied complications related to the conditions. A common symptom of CP covers poor coordination, muscle weakness, stiffness of muscle, and tremors. A motor disorders associated with CP are accompanied typically by issues that

are related to perception, sensation, communication, behavior and cognition along with epilepsy and musculoskeletal complications.^[5]

For addressing the complications faced by children with the movement disorder caused by CP, intervention of assistive technology (AT) is recommended most often. The products of AT are assistive technology device (ATDs) or aids. AT signifies to the device, equipment piece, or the product system designed for enhancing, maintaining, or enhancing functional abilities of individuals with the disorders^[5]. In the AT field, there is a significant gap in research and design targeted at children. Though traditional studies considered the perspectives of caregivers and non-child users, they overlook the needs and insights of children themselves most often. It leads to some products of AT potentially that are not fully meeting practical necessity of children, particularly those with CP who may encounter barriers frequently on utilizing these technologies. A report indicates that children may always fails in utilizing 100's of AT functions.^[6,7] Still, they lack products in mind designed for them which brings user-centered design (UCD) approach to picture.

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In typical, UCD model offers an effectual framework to address the existing challenges. UCD is a multidisciplinary approach which is based on active user involvement to gain clear understandings of user and the task requirement along with design iteration and evaluation.^[8-10] It explores the priorities, needs, and targeted users experiences termed children with movement disorder occurred by CP thus helping designers to create more user-friendly products and designers thereby enhancing user satisfaction significantly. UCD is identified from the understanding of user, their needs, experiences, and priorities leading to improved usefulness and usability of product escalating satisfaction of the user.^[11] UCD usage enables process and research outcomes to be aligned closely with the circumstance and needs of research partakers.

Recently, research on developing and designing AT for the children with CP using UCD approach becomes scarce, representing that this research area needs further development and exploration urgently. Future research might focus on the way that applies UCD principles effectively for identifying and solving desired problems accurately encountered by children with CP on employing AT along with the way to optimize product design continuously over an iterative design and user testing, making them more aligned with the desired requirements of special user groups. Assistive product design plays a crucial part in improving children's comfort, independence, and overall quality of life. These products range from mobility aids for adaptive seating, smart technology, and communication devices.

This in turn offers improved independence, enhanced physical and cognitive development, better social inclusion, reduced burden on caregiver, increased confidence and mental well-beings. The assistive product design for children with CP and mobility impairments bridges a gap among the possibilities and limitations thus making life much more fulfilling and accessible.

There exist several Assistive technologies to design a product for children with CP impairments. Moreover, existing solutions of AT do not address diverse needs of children with CP and their families fully. To address the limitation of existing challenges, AT which includes powered wheelchair and mobility aids shows a crucial part in enhancing accessibility, independence, and comfort. However, traditional AT solution fails in accommodating diverse needs of children due to various limitations. For meeting and resolving these issues, there is a need to develop some conceptual framework to design a powered wheelchair product. The research work intends at developing a conceptual framework to design assistive product effectively by carrying case studies and integrating UCD approach and processes for identifying the key factors to design innovative mobile AT or powered wheelchairs (PW) so as to assist children with movement disorders related to CP. A conceptual framework is then validated by designing AT for children with CP.

2. Literature review

The study carried aims at recognizing the limitation of activity and restriction participation that were encountered by youth and children having disabilities for which the assistive technology and product might be helpful.^[12] A convergent, parallel, mixed model design includes nationwide, French survey that comprises of closed and open that is quantitative and qualitative questions were used which enlightens the quantitative data. A suggestion was provided for facilitating the innovative solution development.

In the work,^[13] intricate interplay among design and AT was highlighted on shedding lights on the challenges faced by the disabled users using those products, specifically CP children. This work explores review indicating in what way these products could affect user's self-esteem, product adoption, and rehabilitation negatively. This in turn underscores the importance of incorporating the semantics and utilizing empathetic models for striking usual balance among functionality and aesthetics in the assistive products design development.

An overview of AT device requirement for children having CP in Malaysia has been provided in the work.^[14] Also, it offers in what way current and prior research on AT device could aid children having CP turns out to be self-reliant at their daily lives.

A development of product needs was suggested regarding the context of AT innovation project.^[15] This is emphasized that AT shows basic role in the sustainable environment and product development since it enables autonomy and inclusion of people having disabilities ensuring entire solutions will be effective and accessible. The initial stage of developing new product will be considered critical because of the need to define the needs which will guide process design.

For enabling the users power wheelchair with the limited mobility for independent and safe charging of their wheelchairs a model was presented in Ref. [16]. The multiple role stakeholders which include potential users, their caregivers and clinicians were engaged with desired relevant expertise in the process of UCD. A resulting wireless charging system enables independent charging while significantly increasing capacity and speed of charging.

The intention of the model presented in Ref. [17] aims at recognizing and understanding the needs and challenges of the parents who needs wheelchair use in relation to the stroller with independent ambulation, and while doing this so as to develop the concept for meeting the challenges and needs. The project attains this intention on applying compilation of double diamond model and Bootleg design thinking design model.

A conceptual framework was suggested in Ref. [18] for identifying the key factors to design the new mobility AT for children having higher mobility impairment occurred by CP. A conceptual framework was developed on identifying key concepts from key variables, literature, data collection, target users, and analysis methods sequentially. In conclude, for designing new AT, children CP characteristics, already

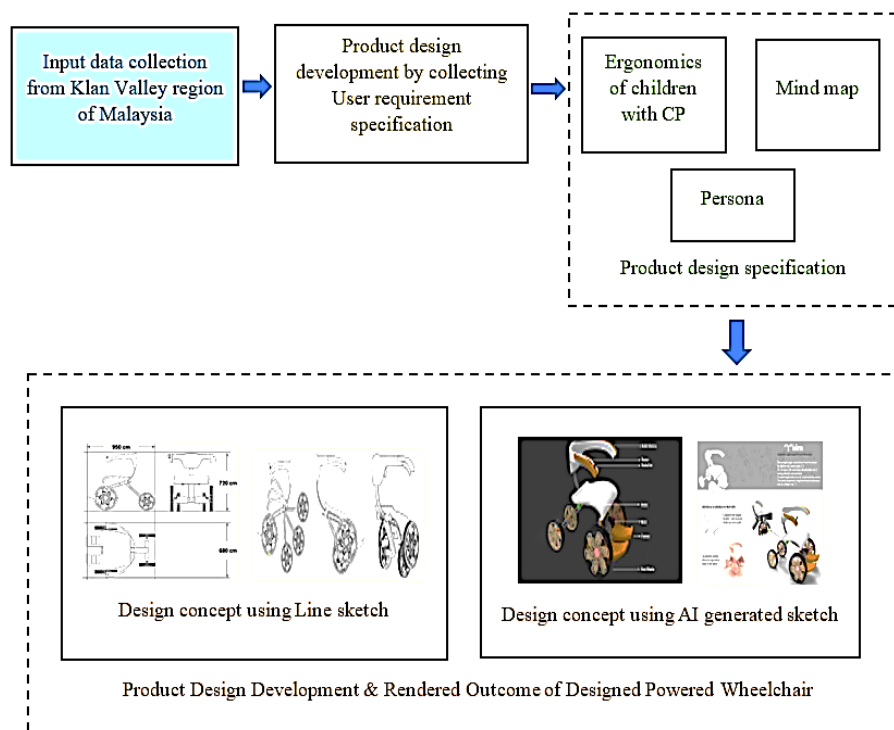


Fig. 1: Process flow or design procedure.

existing ATs along with the factors which influenced its ATs use needs to be considered.

As of the review carried, it is obvious that there exist several Assistive technologies to design a product for children with CP impairments. However, existing solutions of AT do not address diverse needs of children with CP and their families fully. Hence, there is a need to develop some conceptual framework to design a powered wheelchair product.

3.1 Dataset collection

The data is collected from Klang Valley region of Malaysia considered as a site for case study.^[19] As a preliminary step, literature review is carried for knowing the characteristics of children with CP. Then, a survey is carried which includes semi-structured questionnaires and in-depth interviews. In this study, data collection includes gathering of questionnaires and interviews for gathering information regarding user’s needs and characteristic specifically focusing on children having CP and their caregivers. Depending on the outcomes of data collected and analyzed before, needs of children with CP are identified and is transformed as product design specification (PDS) for defining the direction to design a product. This is then followed by utilizing UCD approach for an iterative design.

3.2 Product design development

Once the data is collected and analyzed, design development is initiated which corresponds to UCD cycle portion which specifies needs of user and entire part of product design solution. UCD methodology is an iterative, structured model

which places end-users at design and development process core. In the AT context for children with CP, UCD makes sure that the powered wheelchair is not only functional but too meets the requirement of user like specified mobility, comfort and cognitive needs. The benefits of employing UCD in AT development are enhanced user satisfaction, greater independence, long term usability and sustainability, improved caregiver and therapist support. On leveraging the methodology of UCD, this works aims at developing highly adaptive, user-friendly powered wheelchairs which meets diverse comfort and mobility needs of children with CP. This model ensures that a technology is not merely an effective one but too improves the quality of life, accessibility, and independence of user. Once the user requirement is defined and evaluated, PDS is then developed for defining the design concepts accordingly.

3.3 User requirement specification

From the records of interview and organization integrated with the coding themes and requirements number, standards and significance of needs will be determined after the descriptive analysis. Each need has the clear typical description as shown in Table 1. The needs originated from the interviews and significance ratings depends on questionnaire surveys and interview data, estimated by choice and keyword frequency.

For establishing PDS, design parameters should be defined along with its correlation and needs analyzed for finalizing the definition of product. Table 2 offers relationship matrix among the design parameters and needs, which aids in design decisions.

Table 1: User requirement establishment.

Requirements criteria	Description	Importance
Mobility	Whatever method it takes to achieve this; it should help children with CP to have better mobility	★★★★★
weight	It should be lighter so that even the mother of the children can easily carry it.	★★★★★
Transformable	The function is mainly reflected in the more aspects of handling, especially the scene of carrying to the car and helping the child move from the bed	★★★★★
Adjustable	It should be able to change the size of the part which is in touch with the kid according to the growth of the body of the child using it within a certain range	★★★★★
Ergonomics	Adapt to the ergonomic needs of the user while meeting the premise of adjusting its own dimensions	★★★★★
cost	It should reduce the frequency of changing a new one and the cost of a single product.	★★★★
Aesthetics	It should deliver the children the messages to give them a sense of closeness	★★★
Special use scenarios	Make it easier for children with CP to perform some specific but high-frequency ADLs	★★★
Function integration	Try to integrate functionally with other Atps	★★
Overcome the barrier in surroundings	Easier to overcome some common obstacles	★★★
Accessibility/ Ease of use	It should be easy for children with CP to control.	★★★★★
Safety	Improve the safety of CP children when using it and provide them with a sense of safety	★★★★★
Indoors usage	Consideration should be given to the inconvenience of using it in indoor scenarios	★
Product service	Product services from purchase to maintenance should be more optimized	★★
Variety of products/ Unique	It should give users more choices and unique while meeting their basic needs	★★
Therapy support	It should be able to help complete therapy or rehabilitation	★
Social skill	It should help children have a better interpersonal relationship	★★★

3.4 Product design specification

PDS is an essential and needed definition of which product is needed for the PDS is the essential definition of what the product is required to attain. PDS defines the statement of what the customer needs to attain the product. In this part, series of steps are focused to arrive at final stage of PDS, which includes ergonomics of children having CP, persona, and mind map.

3.4.1 Ergonomics of children with CP

Once the needs of target population are identified, it is essential to consider its physical data. Since AT is close contact with body, it is related closely to the data of body and ergonomics. Table 3 shows the clinical evaluation carried for two distinct children's groups having CP. Each child in group A has been diagnosed with spastic quadriplegia, whereas 30% of group B had spastic-athetoid CP ($p < 0.05$). In addition, entire members in group B will be classified at level 3 of Gross

motor functional classification scale (GMFCS), on comparing to 57% of group A children who fell in this category ($p < 0.05$). This in turn highpoints the variations in motor function levels and the diagnosis among two groups.

A difference in continuous data is compared with the use of independent t-test. The difference in non-parametric data will be identified by means of Chi-square test or Mann-Whitney test * $p < 0.01$ † $p < 0.05$. Anthropometry in a physical anthropology includes human individuals measuring to understand the physical variation. On designing the special chairs for disabled children, it is essential for focusing physical and ergonomic aspects.^[20] Table 4 offers anthropometric data for children with CP.

Table 5 indicates that typical hand dimensions of children are larger than children having CP.^[21] In males, average variation is 16.2% and in females it is 15.5%. The variation is highly pronounced among males.

Table 2: Relationship matrix among needs and design parameters.

Design parameter \ Requirement	Structure design	Material	Size	Color	Finishing	Power Source	Service system	Control	Cloud system	Graphics
Mobility	X		X			X		X		
Weight	X	X	X			X	X	X		
Transformable	X					X		X		
Adjustable	X	X				X	X	X		
Ergonomics	X	X	X		X	X	X	X		
Cost		X	X		X	X	X	X	X	X
Aesthetics	X	X	X	X	X		X			X
Special use scenarios	X		X			X		X	X	X
Function integration	X					X		X	X	
Overcome the barrier	X	X				X		X		
Accessibility	X	X	X			X	X	X	X	X
Safety	X	X				X	X	X		
Indoors usage			X					X		
Product service			X			X	X		X	X
Variety of products	X	X	X	X	X	X	X	X	X	X
Therapy support	X	X	X			X	X		X	
Social skill							X		X	X

Note: * X denotes that there exists a notable relationship among the specified needs and designing parameter. From the ten design parameters, special attention must be paid for structural design, power source, size, control, and materials. These parameters will be related closely to several needs.

Table 3: Demographic and clinical data of children with CP.

Demographic data	Group A(n=14)	Group B(n=13)	P
Age	7.3±2.1	8.9±2.2	0.057
Height (cm)	113.1±8.7	119.2 ±10.6	0.113
Weight (kg)	22.9±5.6	21.1± 3.2	0.344
Gender (male)	10 (71.4%)	5 (38.5%)	0.091
Dominant hand (right) clinical data	8 (57.1%)	10 (76.9%)	0.249
CP types			0.041†
Spastic	14 (100.0%)	9 (69.2%)	
Spastic-athetoid	0 (0.0%)	4 (30.8%)	
GMFCS			0.009*
Level 2	6 (42.9%)	0 (0.0%)	
Level 3	8 (57.1%)	13 (100.0%)	
Upper limb function			
Proximal: Shoulder/elbow			
Upward rotation (%) distal: hand	89.3± 4.5	85.6 ±4.7	0.047†
Finger opposition (%)	78.6 ±27.5	75.0 ±39.5	0.786
Muscle strength			
Shoulder flexor	3.43 0.76	3.85 0.38	0.102
Elbow flexor	3.21 0.80	3.62 0.51	0.186
Wrist flexor	3.29 0.61	3.31 0.75	0.830
Finger flexor muscle tone	3.36 0.50	3.23 0.83	0.830
Shoulder flexor	0.43 0.85	0.69 1.03	0.398
Elbow flexor	1.89 0.45	1.35 0.83	0.029†
Wrist flexor	1.86 0.36	1.46 0.48	0.019†
Finger flexor	1.61 0.59	0.69 0.85	0.009*

Table 4: Sample of physical body measurement.

Description	Measurement (mm)
Height neck to head	200
Shoulder length	240
Waist width	150
Waist to knee	250
Waist to toe	460
Armpit to waist	290
Armpit to stomach	150
Length of leg	140
Head width	140
Knee to toe	210
Butt to knee fold	260
Leg fold(knee) width	90

3.4.2 Mind map

A mind map is a figure or schematic diagram that is employed to visually organize information, thus presenting it hierarchically, showing relationships among the entire parts.^[22]

Here, a mind-map in Table 6 is used for depicting the process of problem-solving ideas and processes.

Primarily, a solution to the problem has been provided for CP children and caregivers, which was often encountered from the analysis of previous needs that were employed for defining product functionality that is defined initially.

3.4.3 Persona

Though the typical needs and characteristics of children with CP were understood, the use of Persona could guide product design more specifically for meeting user needs. The personas are the fictional illustrations constructed depending on behavioral information and user demographics, which represent the kinds of users who might use a brand, product, or site similarly. Here, two Personas are created using 2 children with CP as shown in Figs. 2 and 3. These Personas depend on the description from the participants interviews with their children, and children having CP are divided as two categories as per the learning abilities and mobility.

Table 5: Comparison of mean values between male and female.

Dimension	Male		Difference (%)	Female		Difference (%)
	Normal	CP		Normal	CP	
Hand length	130.6	121.5	7.5%	129.9	117.0	11.1%
Palm length	74.2	65.2	13.8%	73.5	64.7	13.7%
Palm width (metacarpal)	61.7	61.2	0.8%	59.5	59.1	0.7%
Palm width (until thumb)	73.1	68.2	7.2%	72.3	65.9	9.7%
Thumb length	44.3	41.3	7.3%	42.8	42.2	1.4%
Index finger length	50.9	50.2	1.3%	51.0	48.8	4.5%
Middle finger length	58.5	56.0	4.4%	56.4	52.3	7.8%
Ring finger length	52.1	50.6	3.0%	51.1	51.0	0.1%
Pinky finger length	41.0	44.3	8.0%	39.3	42.2	7.3%
Thumb width	17.5	12.8	36.5%	16.3	12.9	26.4%
Index finger width	15.4	11.6	32.8%	14.4	11.7	22.7%
Index finger thickness	12.5	11.6	7.5%	12.9	12.0	7.8%
Palm thickness (metacarpal)	21.3	15.9	34%	21.3	14.5	46.8%
Palm thickness (until thumb)	24.5	21.8	12.5%	25.5	23.9	6.7%
Max width (thumb until pinky finger)	148.7	127.2	16.9%	145.7	133.8	8.9%
Max functional width	128.5	93.5	37.4%	134.9	110.8	21.7%
Max grip diameter	28.7	21.9	31.4%	29.1	23.5	23.5%
Min grip diameter	13.9	10.0	39.3%	14.4	9.0	60.0%
	Average		16.2%	Average		15.5%

Table 6: Representation of mind map-problem solving board.

Problem	Idea
Upstairs requires a helper	Special wheels structure Portable ramp Structure for move
Hard to move from bed to AT	Remote control Calling for parental help
The height between the wheelchair and the desk are not fit	Adjustable structure of height Portable desk
Some outdoor activities cannot be participated in like others	Function for certain activities The additional system for personal relationships
If leave the AT, the kid will find it hard to get approach it.	Function for climbing the AT
Lack of a sense of safety	A special form that can provide a sense of safety
Hard to have friends	The additional system for personal relationships Better icon design of AAC
Learning difficulties	Better surface design for AAC Better touch surface/ button
The barrier from the environment	Function to overcome special environments Better control of AT Smaller size
Indoors movement hard	Foldable The functions of different ATs can be combined together
Hard to express requirements	Better design of AAC
Weakness of upper limbs	Better design for AT control
Hard to control AT	Better design for AT control
AT purchase method	Various purchase method Customized systems
Ergonomic problems caused by the growth	Adjustable sitting frame Structure design of sitting frame
AT choice less than adults	More concern of children
The reference to AT change	More contact with doctor Foldable structure
Some ATs are hard to carry	Special foldable structure that helps to carry the AT to the car
The pain when using AT	Better material of the contact part of the AT
Some ATs are too big	Foldable Structure Design for children
Cost of AT	Cost-saving materials Cost-saving structure Cost-saving finishing

To summarize, targeted children with CP must be at the level III of GMFCS in relation to functional mobility, needing functional AT like wheelchairs. moreover, they possess certain degree of independence and are not affected severely by CP related conditions such as communication and learning complication which could render them entirely unable to utilize these devices independently. They have some upper limb muscle dysfunction but do not suffer from severe spinal issues which might outcome in little independence.

4. Results and discussion

From the above considered needs and specification carried from survey and questionnaires, the product design

development is made. This section delivers information regarding the development of product design and its outcomes.

4.1 Developing product design specification

PDS is defined as a detailed document representing precisely what a process or product must present. PDS illustrates the needs and requirements of user or customer for attaining their product. PDS should be prepared in each case for serving as a reference to design the objective.

Table 7 is the representation of product design specification, which comprises five major aspects like function, performance, environmental setting, materials, and participation, which is expected to help children with CP.



Fig. 2: Persona-1.

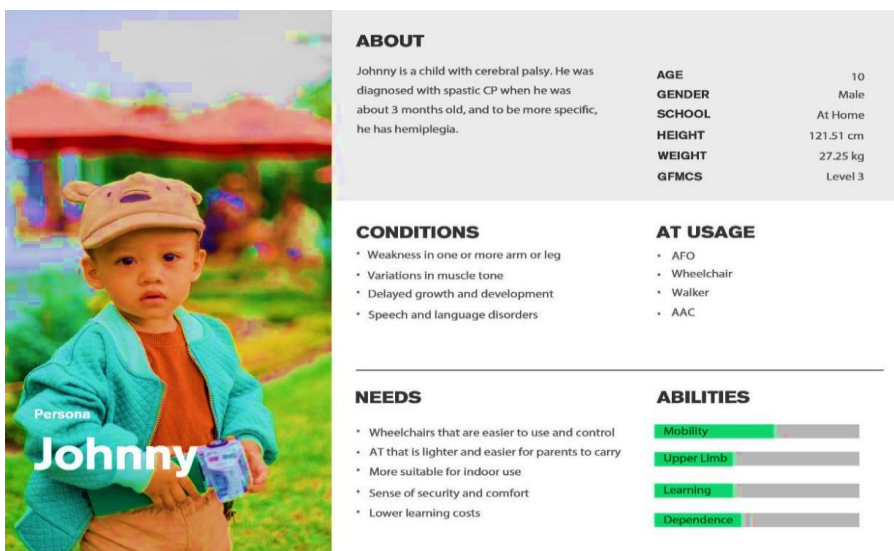


Fig. 3: Persona-2.

Table 7: Product design specification.

Function	Transformable/ Foldable/ Adjustable Interactive Interface Mobility Aid
Performance	Size: Height 850-1110 mm Width 605-725 mm Length 690-740 mm Weight: 10-20 kg Power supply: Battery
Environment setting	School House Condominium
Material	Steel Aluminum Plastic
Participation	Provide the ability to move Independently

Based on these specifications considered, a design concept is carried for designing powered wheelchair and is described in detail in the subsequent section.

4.2 Design concept

A PW is designed specifically for addressing the insufficient upper limb muscle strength in children with CP. This in turn features a simple design structure, thereby avoiding the complex components which is suitable for children with minor spinal related impairments, needs minimal upper limb movements. For this purpose, “Y” structure is utilized for reducing the weight by integrating electronic parts to lower section for enhancing the stability. This PW includes adjustable and foldable features for portability for meeting the transportation needs among varied location and buildings, thus reducing the burdens of children and parents. These improvements are carried based ion the survey so as to ensure the practicality and convenience of AT the time of car transportation. Fig. 4 shows the “Y” structure designed.

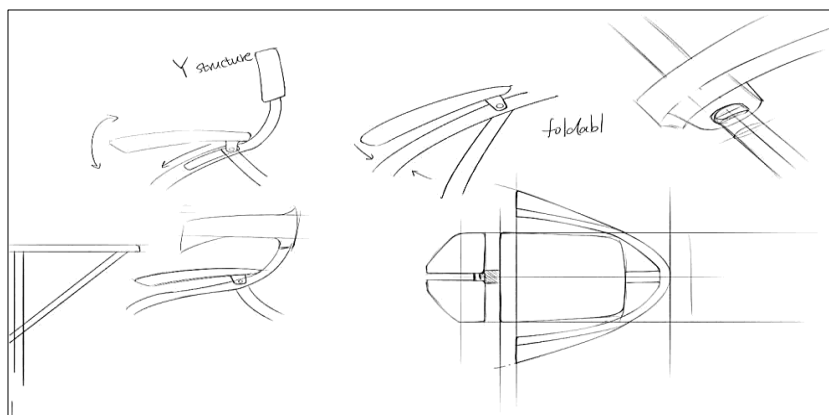


Fig. 4: 'Y' Structure.

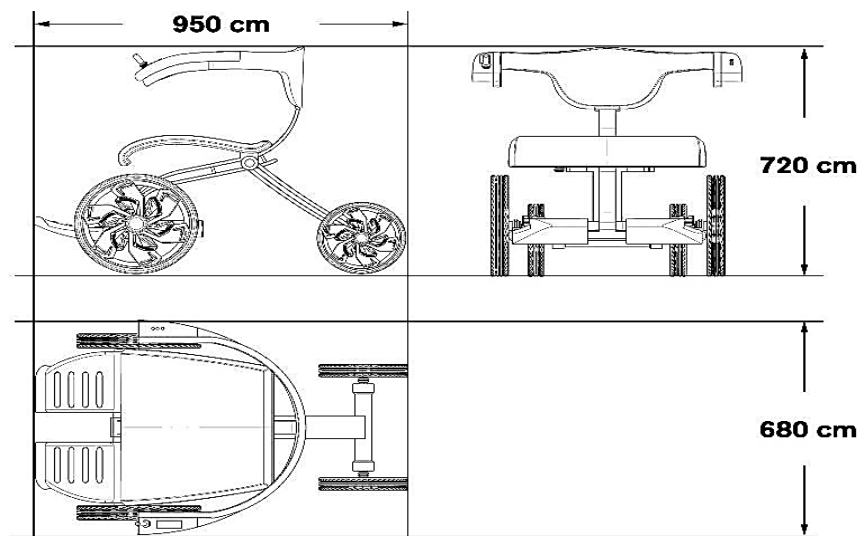


Fig. 5: Designed wheelchair's size and dimensions.

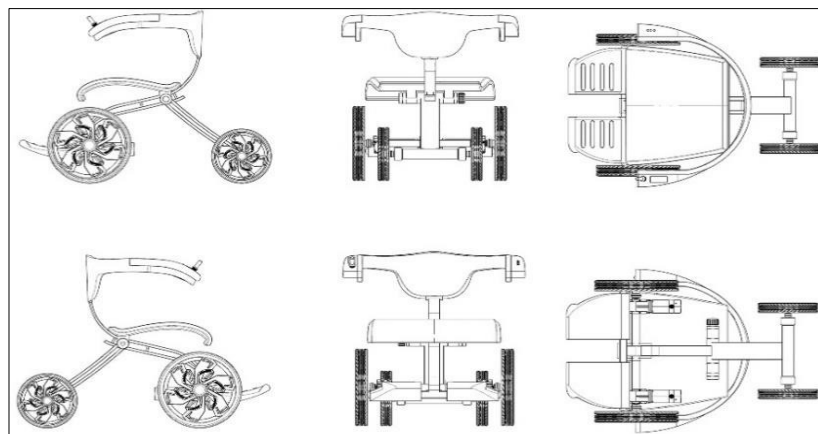


Fig. 6: Six views.

The significant advantage of this structure lies in its adjustable angle and height. main frame's central part is thus designed with space for adjustment thus allowing them for flexible variation in heights and positions of seat cushions and rear wheel bracket. In addition, angle adjustment might also modify height, which ensures more comfortable back support for user. Those features are thus realized in subsequent detailed designs as represented in Fig. 4. Then, a 3D model is built from sketches. The dimension of entire PW is shown in

Fig. 5, which shows that overall height is 72 cm which is a minimal height to utilize the product. The information provided is based on the measurement of physical body sample from CP children as mentioned before in previous section. Fig. 6 shows the designed PW's six views and their adjustability shown in Fig. 7.

A control lever of the designed electric wheelchair is employed for controlling the speed and direction having length of approx. 40 cm. Depending on the width of palm in

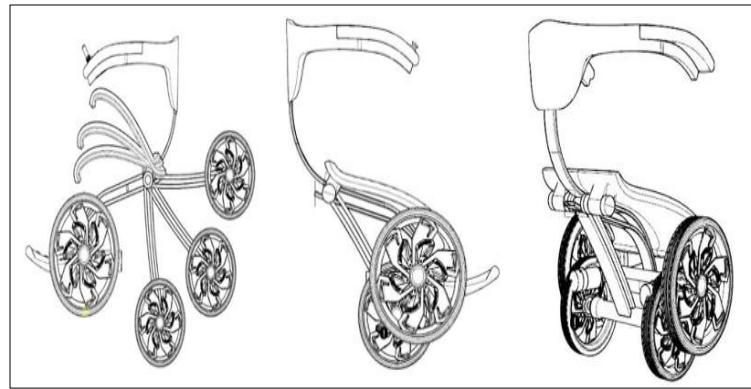


Fig. 7: Adjustability.

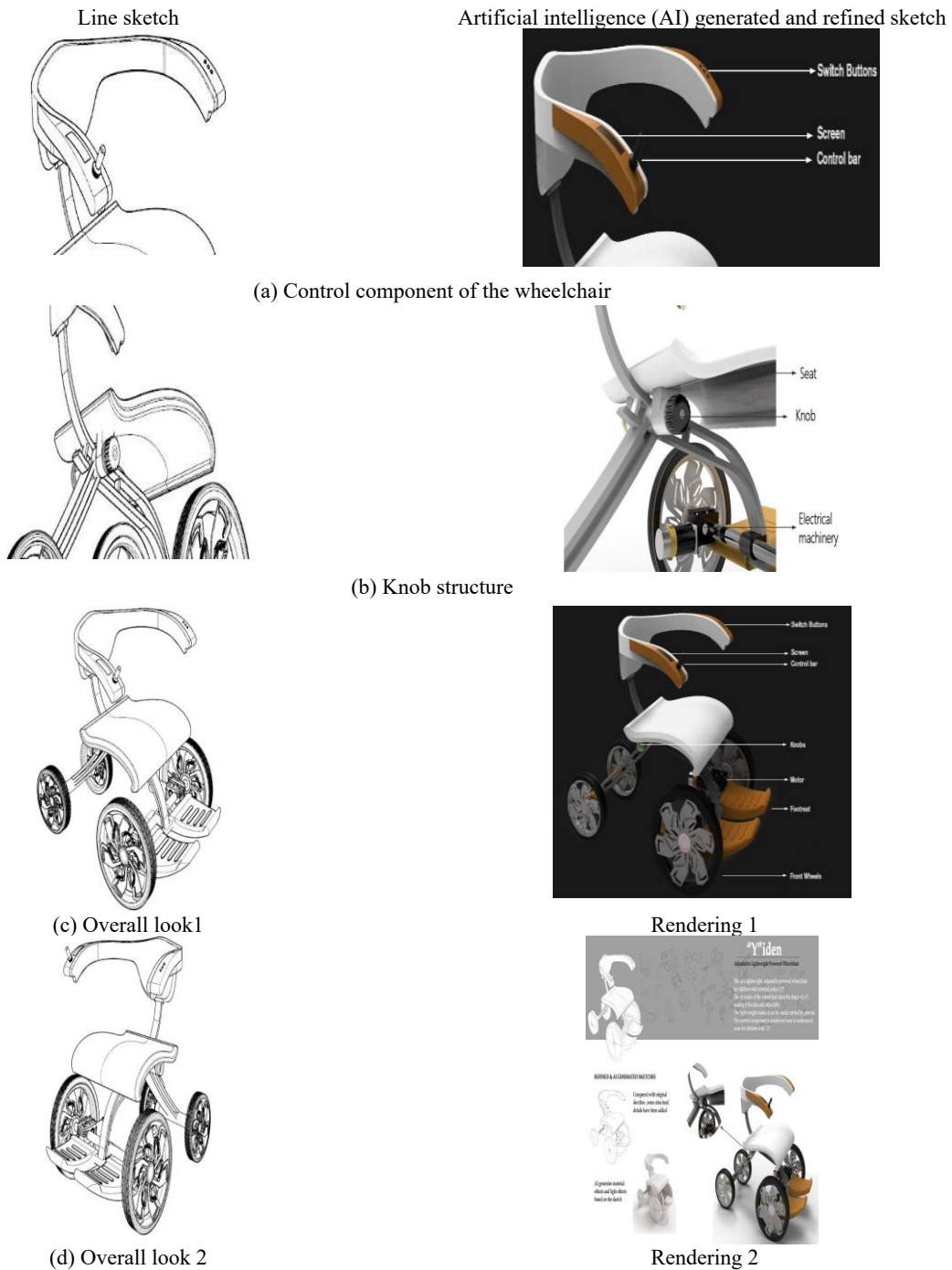


Fig. 8: Representation of designed product with line sketch and their corresponding AI generated sketches.

children with CP (both females and males are about 6 cm), length of control lever will be the two-thirds of width of the palm thus making them easy to apply forces with the use of upper and lower parts of palm.

Fig. 8 is the representation of designed product with line sketch and their corresponding AI generated sketches. Thus, a powered wheelchair design using UCD approach is shown which will aid in rectifying the burdens of children with CP and their caregivers more effectively.

5. Conclusion

In this article, a conceptual framework was developed by carrying case studies and thereby integrating UCD approaches and processes for identifying the key factors to design innovative mobile AT or powered wheelchairs for assisting children having movement disorders relating to CP. Regardless of existing geographical issues and challenges, this model offers valuable insights to design AT for children with CP. A data is being sourced from Klang Valley region of Malaysia and efforts were carried so as to remain objective in analysis for minimizing the regional biases. The intention was to design universal AT which was not targeted towards specified regions or family backgrounds. Initially, the characteristics and needs of user were identified by carrying surveys, interviews, and questionnaires' by combining UCD approach. Then, from this collected data, design concept with product design specification and development was carried to attain final decision on designing a product. From this, a line sketch is made and finally AI generated sketch of designed product is rendered effectively.

Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

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