Conceptualization and Ergonomic Analysis of a Typical Unicycle

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Abstract— An unicycle is a fast growing vehicle for undergoing transportation. Due to several advantages of unicycle when compared to other vehicles, an effort is made in this work to study the existing design of unicycle in the Indian market and provide the comfortable drive to the unicyclers. The existing design lacks on the prospects of stability and safety. The drawbacks identified in the existing design were concentrated as critical aspects in this work. The critical aspects include forward and backward stability, uncomfortable rider posture-handle bar -pedal relations. For maintaining the stability, continuous human attention and control is needed otherwise it may lead to the fatigue problems to the rider who rides the unicycle. The concepts were generated using freehand sketches to resolve the problems in existing design. The concept evaluation has been done using Pugh chart selection matrix. The selected concept is modelled using CAD software and ergonomic analysis is done using CATIA V5 using the Indian anthropometric data.

Index Terms—Stability, Safety, Fatigue, Unicycle.

1 INTRODUCTION

THE objects of utilitarian value to people is created by the product design process. It involves the understanding of materials , processes, ergonomics , human behaviours and system. The role of the product designer is to identify the problems in the existing design and come out with the solutions that could impress the end user. The application of problem solving methodology in design supports to obtain the end results .

The problem solving methodology in design consists of the following steps

- Definition of the problem
- Gathering the information
- Generation of alternative solutions
- Evaluation of alternative
- Communication of the results.

The definition of the problem is the detailed statement of the problem faced in the existing design of the product. Gathering of information is the collection of specific and current information regarding the product from journals, patents, catalogues, handbooks and literatures published by vendors.

The generation of alternative solutions depends on the creative thinking capability of a designer.

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The ability to generate high quality alternative solution is vital for a successful design. The evaluation of alternative solution consists of systematic methods for selecting the best among several designs . Simulation of performance with computer models is finding wide usage.

The communication of results involves a written design report details the 3D model dimensions and analysis of the product at the end of the project which should satisfy the need of the customer.

2 CRITERIA FOR EVALUATION IN THE EXISTING DESIGN

The existing unicycle's design procedure and performance are deeply evaluated to understand the various limitations associated with it. Generally, in a typical product development process, the product is evaluated based on a specific set of design criteria. The design criteria are framed with regard to cost, functionality, safety, maintenance, durability, availability, in addition to a specific set of criteria depending upon the product being considered.

A specific set of criteria for the design of comfortable unicycle is considered and the existing unicycle's design and performance are evaluated to understand its limitations.

Depending upon the shortcomings of the existing product for the criteria considered new designs are proposed to overcome the limitations. In this work, the formulated criteria for the comfortable unicycle design and its evaluation mainly based on the driving methods , stability of drive condition, portability, ease of transportation , compactness, material used, tire size, weight, etc.. The formulated set of criteria's which overcome the shortcomings in the existing design strengthened the need for a new comfortable unicycle design.

2.1 Difficulties faced in Existing Unicycle

Forward and backward instability problems are reported while riding the unicycle. Sudden turning skids the rider and leads to instability problem. Discomfort faced in riding such as handle reach, saddle to ground height, saddle-knee-pedal reach leads to customer dissatisfactions.

2.2 Objective

The drawbacks of the existing design are to be surpassed with the new innovative concepts as a designer. The focus is to develop a unicycle with good stability, safety which fits into Indian road conditions. Also, the cost of the product should be affordable to the middle class group in the Indian population.

2.3 Literature review

In this stage review of various journal publication , patterns ,electronic media, conference proceeding paper and technical reports about improving the above mentioned problem definition related work especially on the stability. [1] In 1987, Michael J. Whelan remodeled a ball cycle by providing cushioned concave rubber bumpers on each end of main axle in a motive to reduce the risks faced by the rider. [2] In 1957, Marjorie E. Phillips has invented a concept of adjustable balancing supports to the unicycle in order to maintain equilibrium of the rider. The main aim of this concept is to auxiliary wheel when the rider is unbalanced. [3] This concept provides an auxiliary device which can connected to a main fork of an unicycle for easy learning. [4] Leonard E. Bensette, et.al designed a unicycle for greater stability and to reduce lateral unbalance using water balance .which is also be used better practical training. [5] In 2008, Peter Greenley, et.al has invented a mono-wheel vehicle with tilt mechanism to turn the rotating wheel. [6] In 2011, Yu-Gang Chen invented a unicycle with auxiliary wheel mounted on each ends of the rear wheel hub enables convenient folding position adjustments. [7] Zaiquan Sheng, et.al developed the experimental result shows the prosed fuzzy gain schedule PD controller is valid for the robots postural stability control. [8] Y.Yavin has described the path of improve stabilization and guidance of the system which is composed of disc rolling on a plane using the concept of increase control transformation and basic concept of path controllability for single wheel aspect. [9] in1998, Dmitry V.Zenkov , et.al studied the analysis stabilization of a non-holonomic system consisting of a unicycle with rider. In this they have showed that the rider can achieve stability of slow steady vertical motions by imposing a feedback control forces. [10] Chung-Neng Huang, developed a self-balancing controller (SBC) for one-wheeled vehicles (owvs). The composition of the OWV system includes: a DSP motion card, a wheel motor, and its driver. In order to realize self-balancing controls a tilt & a gyro are used to sensing the angle and angular velocity of the body slope. [11]1n 2015, Robin s. Sharp, developed a mathematical model of a unicycle with rider to control the yaw, pitch and roll torques. [12] Sam Kaplan, designed a self-balancing bicycle for a disabled person to ride a bicycle using gyro wheel concepts.

It is evident from the literature study that many authors have focused on the problems of safety and instability in the unicycle. In this work, an economic design considering cost as major criterion, the conceptual ideas are generated and selected to solve the issues of safety and instability in the existing design of unicycle in the Indian market. The comfort level of the proposed design is checked by ergonomic analysis using RULA CATIA V5 software.

3 CONCEPTUAL DESIGNS

It is the art of the designer, thinking about the problem in the existing design comes out with different ideas which are recorded in turn through conceptual sketches, the steps involved in the conceptual design stages are shown in Fig 1. The very important step in the product development process is so called conceptual design.

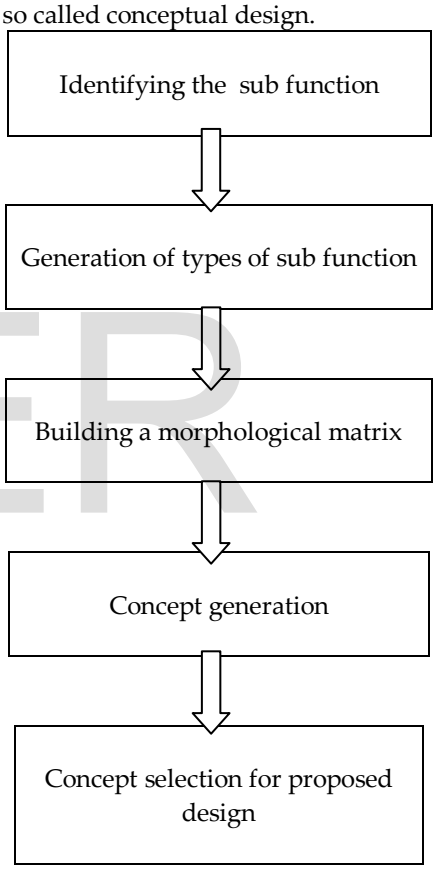


Fig. 1. Conceptual Design Activities

3.1 Identifying the sub function

In this stage of conceptual design various sub functions needed to build a concept are identified. Generally, these sub functions are identified using the existing design function diagram.

Unicycle's sub function is usually identified with the help of existing unicycles and other bicycles functional diagram.

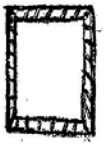
SOLUTIONS / SUB FUNCTION	Solutions 1	Solutions 2	Solutions 3	Solutions 4	Solutions 5	Solutions 6	Solutions 7
FRAME SECTION	 O Shape	 Ellipe Shape	 I-Shape	 C-shape	 Triangle Shape	 Square shape	 H-Shape
JOINTS	 female & male joint		 Wild Joint	 Rivet			
FRAME	 Small tubes	 Big tubes		 Truss Frame			 Cantilever Frame
LINKS	 Box link	 Single link	 Extra link	 Ball joint	 coupling link	 universal joint	
FORKS / STEERING							

Fig.2a. Morphological Chart of Unicycle

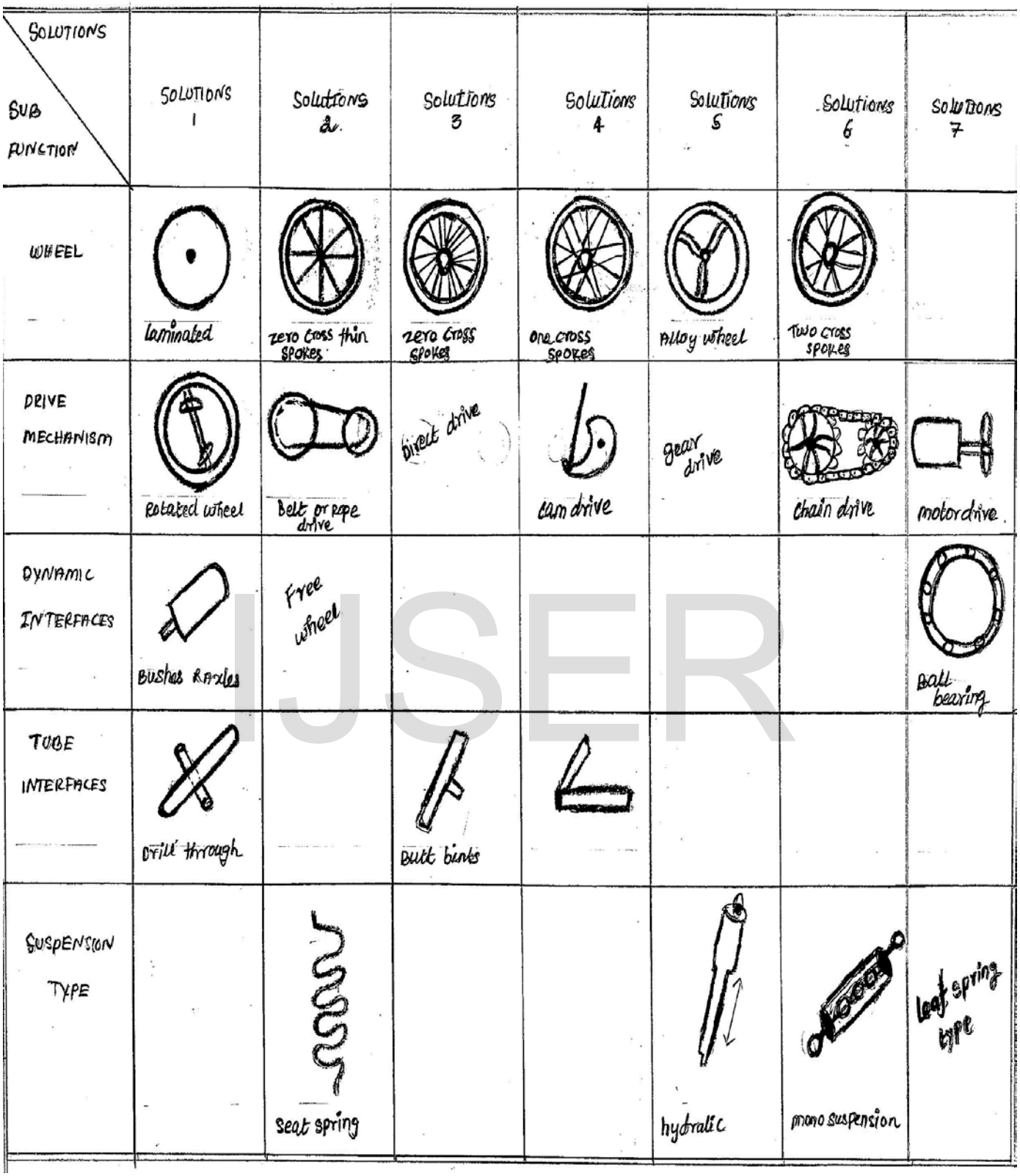


Fig.2b. Morphological Chart of Unicycle

Sub functions identified to build a comfortable unicycle are section, joints, frame, links, handle bar, wheel, drive, dynamic interface, tube interface and suspension.

3.2 Generation of types of sub function

Sub function has a variety of solutions or mechanisms. Here we have to draw the symbolic diagram of each sub function which includes the past as well as latest solutions using sketches. For example, the drive is a sub function, whereas, chain drive, direct drive, cam drive, etc., is its solutions.

3.3 Morphological matrix

Each sub function is arranged in a table form called morphological matrix it's shown in Fig.2a & 2b. It has n*n elements. It is used to build a n number of new unicycle design concepts by choosing a particular sub function with its solution to solve a particular design constraint. For example (1, 1)+ (2,2)+ (3,7) + (4,6)+ (5,3)+ (6,5)+ (7,3)+ (8,7)+ (9,1)+ (10,6), maybe choose as a design concept to solve a particular problem. Thus, in the parentheses the first number indications sub function type and the second number indicate the solution associated with the particular sub function as taken in the morphological matrix.

To be clear on the concept taken in the design of unicycle (1,1) indicates first sub function type in the morphological matrix as frame section and the next number in the parentheses '1" indicates the solution in the matrix as circular section. Therefore, for this particular design considered the frame section as circular section. Likewise (2,2) indicates joint design with threaded joints, (3,4) indicates frame design with truss frame and so on for arriving the entire design of the unicycle with best chosen parameters of various sub functions and its solutions.

4 CONCEPT GENERATIONS

To create "n" number of possible concept combinations for the design of better comfortable unicycle with the help of morphological matrix. Brainstorming and free hand sketching are the arrival methods used here for the concept generation techniques. Sometimes it gives an innovative solution or mechanism idea for solving design problems. Some of the six feasible combinations for the good comfortable unicycle design are tabulated in the below Table 1. Based on the six concepts and their short description of each concept are discussed as follows:

4.1 Conceptual sketch 1

It involves a proposed comfortable unicycle design created from the combination and freehand sketching:
(1,1)+ (2,2)+ (3,7)+ (4,6)+ (5,3)+ (6,5)+ (7,3)+ (8,7)+ (9,1)+ (10,6).

Description:

Mono suspension provided at the both sides for customer comfort. Adjustable seat and handle ensures ergonomic design. An auxiliary wheel at the front of the unicycle improves the prospects of customer stability and safety. Links 1, 2, 3, & 4 are attached through a thread joint. In this concept developed with direct drive mechanism, it is shown in Fig.3.

4.2 Conceptual sketch 2

It is shown in Fig. 4, it is created from the combination:
(1,1)+(2,3)+(3,7)+(4,5)+(5,4)+(6,5)+(7,3)+(8,7)+(9,1)+(10,6).

Description:

In this design, handle bar is fixed and adjustable seat ensures customer comfort. Mono suspension provided at the both sides of wheel to reduce the vibrations. The additional link is attached to the seat tube for improving the stability and safety. This concept is developed with direct drive mechanism.

4.3 Conceptual sketch 3

It has been generated from the combination:-
(1,1)+(2,3)+(3,2)+(4,5)+(5,6)+(6,2)+(7,3)+(8,7)+(9,3)+(10,2).

Description:

Design resembles the letter capital m type. Inbuilt seat suspension and adjustable handle bar to the ergonomic prospects, handle bar in this design. The sliding links are provided at the top and front of the unicycle which controls the auxiliary wheels and ground clearances. Direct drive mechanism used in this concept, as shown in Fig. 5.

4.4 Conceptual sketch 4

It involves a proposed comfortable unicycle design it is shown in Fig. 6. It created from the combination:
(1,1)+(2,2)+(3,4)+(4,5)+(5,5)+(6,5)+(7,3)+(8,7)+(9,1)+(10,2).

Description:

The seat structure is provided by the leaf spring type suspension as in four wheelers. The seat structure and handle bar is adjustable for enhancing customer comfort.

The entire unit can be easily dismantled. Two auxiliary wheels are provided at one end attached to the tube which runs through the gap between the wheel and adjustable seat unit. The v type frame is provided with small pins to enclose the structure together.

4.5 Concept sketch 5

It involves a proposed comfortable unicycle design created from the combination:
(1,6)+(2,3)+(3,7)+(4,5)+(5,5)+(6,5)+(7,6)+(8,2)+(9,3)+(10,2).

Description:

The frame which connects the auxiliary wheels at the front and back is a single structure resembling the letter small x. The design reduces the use of fasteners at the centre of the structure a chain drive mechanism is provided. Adjustable seat and handlebar enhances the customer comfort which is also included in the design. Auxiliary wheels are provided for balancing, which

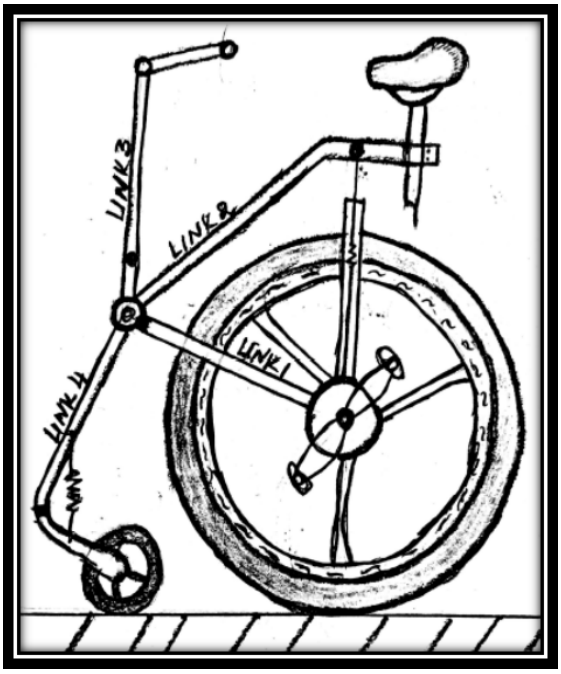


Fig.3. Conceptual Sketch 1

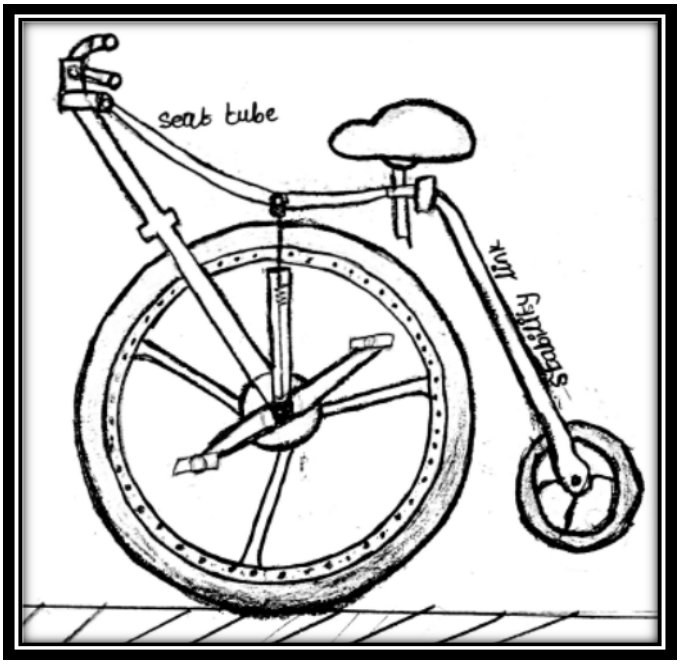


Fig.4. Conceptual Sketch 2

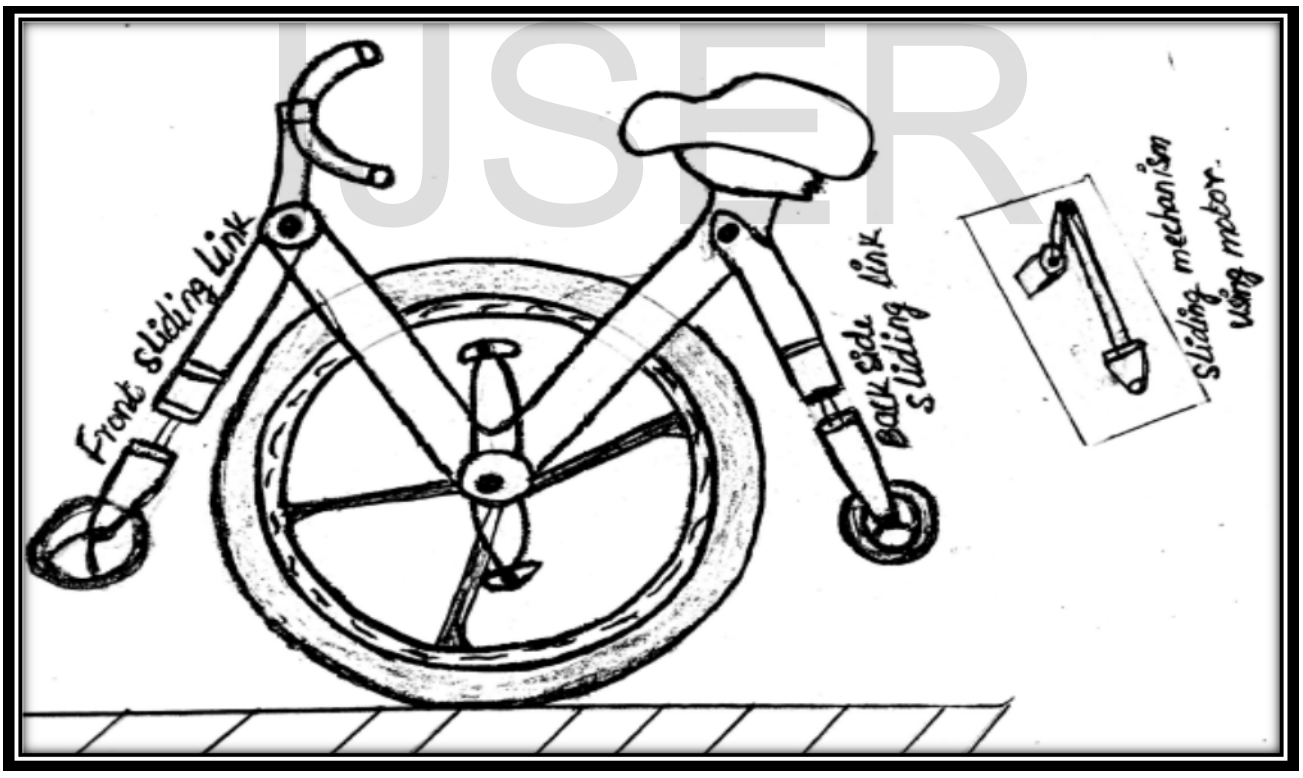


Fig.5. Conceptual Sketch 3

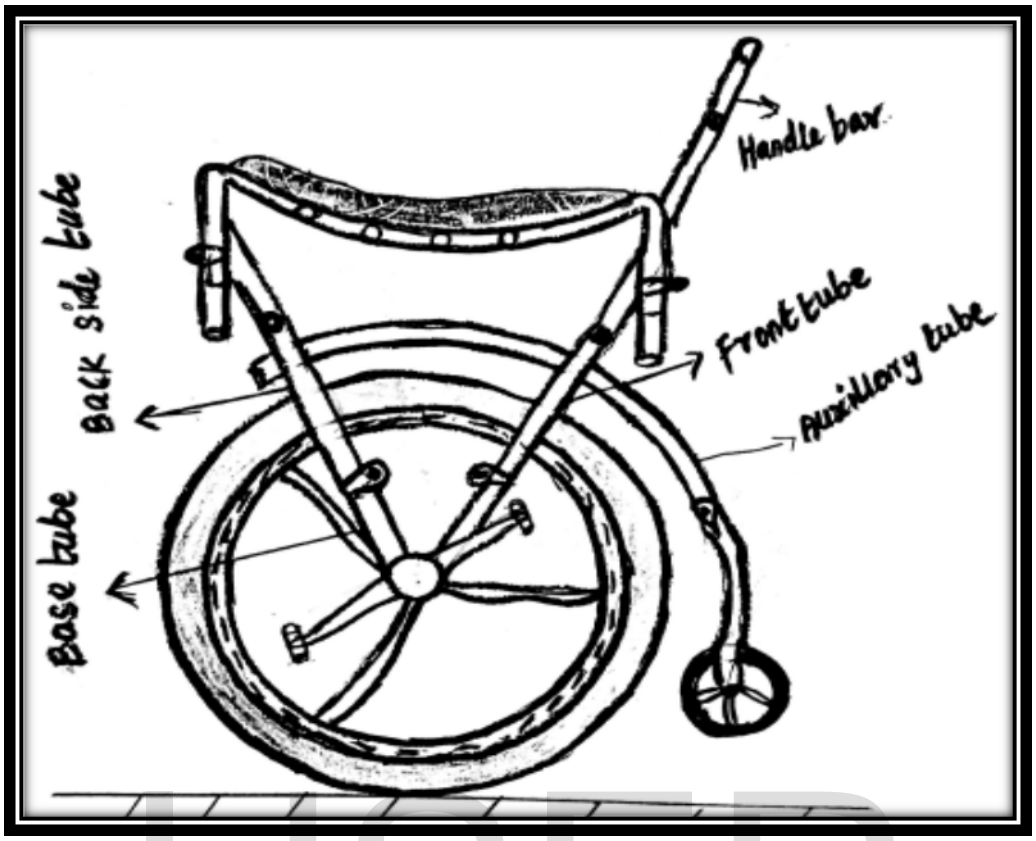


Fig.6.Conceptual Sketch 4

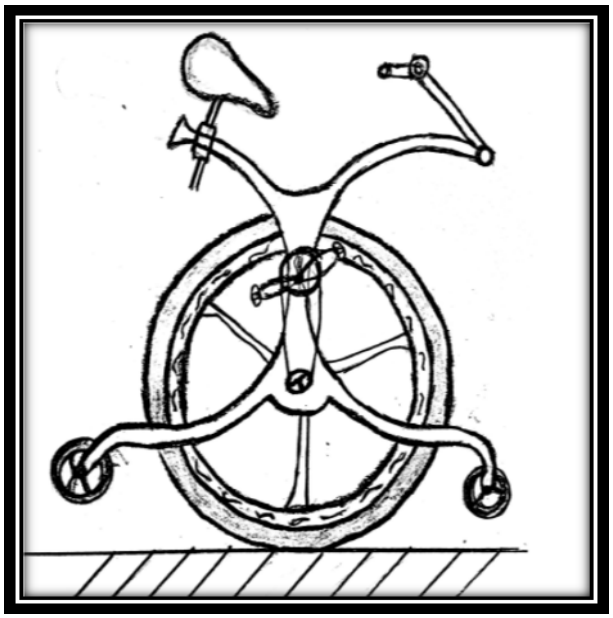


Fig.7. Conceptual Sketch 5

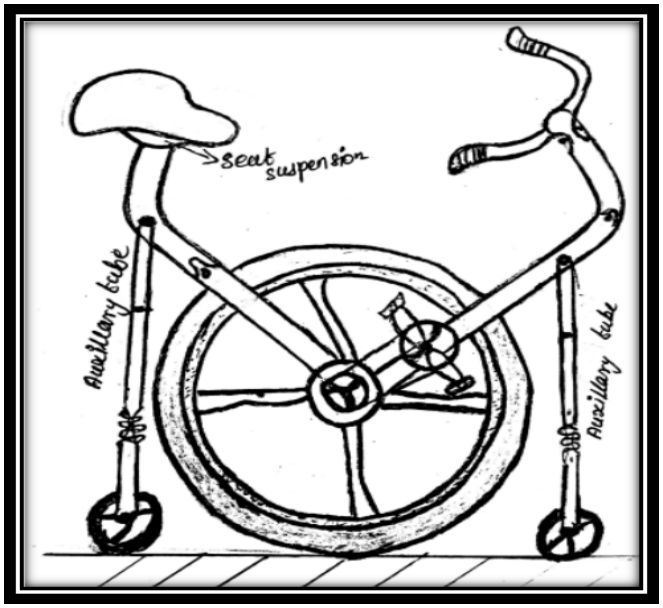


Fig.8. Conceptual Sketch 6

TABLE 1
COMBINATION MATRIX FOR CONCEPTUAL SKETCH

Concepts	**Combination Matrix for Conceptual Sketches**
Conceptual sketch 1	(1,1)+ (2,2)+ (3,7) + (4,6)+ (5,3)+ (6,5)+ (7,3)+ (8,7)+ (9,1)+ (10,6).
Conceptual sketch 2	(1,1)+(2,3)+(3,7)+(4,5)+(5,4)+(6,5)+(7,3)+(8,7)+(9,1)+(10,6)
Conceptual sketch 3	(1,1)+(2,3)+(3,2)+(4,5)+(5,6)+(6,2)+(7,3)+(8,7)+(9,3)+(10,2)
Conceptual sketch 4	(1,1)+(2,2)+(3,4)+(4,5)+(5,5)+(6,5)+(7,3)+(8,7)+(9,1)+(10,2)
Conceptual sketch 5	(1,6)+(2,3)+(3,7)+(4,5)+(5,5)+(6,5)+(7,6)+(8,2)+(9,3)+(10,2)
Conceptual sketch 6	(1,2)+(2,3)+(3,2)+(4,5)+(5,1)+(6,5)+(7,6)+(8,2)+(9,1)+(10,2)

TABLE 2.
THE CONCEPT EVALUATION AND SELECTION USING PUGH CHART

Pugh Concept Selection Chart							
Criteria	Datum	Concept 1	2	3	4	5	6
Criteria 1 : Ease of Maintenance	0	-	-	+	+	+	+
Criteria 2 : Affordable cost	0	-	-	+	+	-	+
Criteria 3 : Ease of manufacturing	0	+	-	-	+	-	-
Criteria 4 : Easy to use	0	+	0	+	+	0	+
Criteria 5 : Joints and links	0	-	-	-	-	-	-
Criteria 6 : Good portability	0	-	-	-	+	+	-
Criteria 7 : Good Ergonomics	0	+	+	+	+	-	+
Criteria 8 : Ease of Adjustability	0	+	+	-	-	-	-
Criteria 9 : Good Speed	0	+	-	+	-	+	+
Criteria 10 : Good Aesthetics	0	+	+	+	+	+	+
S-		- 4	- 6	- 4	- 3	-5	- 4
S+		+6	+ 3	+ 6	+ 7	+ 4	+ 6
S		+2	-3	+2	+4	-1	+2
Selected sketch	Selected sketch 4						

touches the ground only in care of instability, it is shown in Fig. 7.

4.6 Conceptual sketch 6

It has been generated from the combination:-
(1,2)+(2,3)+(3,2)+(4,5)+(5,1)+(6,5)+(7,6)+(8,2)+(9,1)
+(10,2).

Description:

It shows fixed seat and adjustable handle bar for customer comfort. Auxiliary wheels are attached to the v type frame at the front and back end of the wheel. Mono suspension is provided on auxiliary wheel tube to reduce vibrations in this concept shown in Fig 8, is developed with chain drive mechanism.

5 Concept evaluation and selection

The word evaluation here it means both comparison and decision making regarding the ideas generated in the concept generation stage. The evaluation methods differentiate the concepts generated and list the criteria that should be met by those concepts for selecting them. It is also the convergence stage of concept development. In this way, the "best" design for our problem could be arrived.

5.1 Pugh chart

A Pugh chart is a concept selection tool using the minimum evaluation scale (-,+,s). The design criteria are listed in the left hand side of the table (column wise). The concepts or ideas at the top of the table (row wise). The datum is the reference (may be competitor product) or our own product with a better performance (or) features. The scale (-,+,s) is used for rating different concepts against criteria. "-"indicates worst design than datum. "+" indicates better design than datum. "s" or "0" indicates same as the datum. Σ+ve , Σ –ve and Σ avg is done for each and every concept. The one with the minimum number of "-"points, highest number of "+" points and the better average score is selected as the best design.

The concept evaluation criteria are Ease of Maintenance , Affordable cost, Ease of manufacturing, Ease to use , Joints and links , Good portability , Good Ergonomics , Ease of Adjustability , Good Speed and Good Aesthetics etc..

The concept evaluation and selection using Pugh chart is shown in Table 2. For example the "-ve" sign for the concept 1 against the criteria, ease of maintainability indicates that it less easy than the data existing model. Likewise the rating should be performed for several other design concepts with respect to the criteria considered. After the rating is done for six feasible combinations or concept, it is concluded that concept 4 has the highest value of points as "4" when compared with other design approaches. This concept 4 is regarded as the best model to implement the comfortable unicycle.

6 ERGONOMIC EVALUATION OF PROPOSED DESIGN

In this stage, the ergonomic aspects of the proposed unicycle are evaluated using virtual CAD environment. Here the postural evaluation of the proposed design is done by DHM method based on the RULA analysis. The RULA analysis score indicates to determine the optimal design, configuration [14] of a unicycle based on the ergonomic perspective. The proposed design Indian anthropometric data [13] percentile is used, which is shown in Table 3.

Here, handle bar reach, saddle –knee clearance & pedaling reach, seat saddle to ground dimensions are mainly considered to evaluate the proposed unicycle design which shown Fig.10,11,12.

The main objective of this analysis is to find ways to improve the final product design and to prove the proposed design has human conformance & effectiveness.

The ground to saddle dimension considers anthropometric data of buttock to leg full external length, normal stand height, whereas the handle reach considers anthropometric data's of hand length, arm reach mid position length, upper position length, and lower position length. Finally the saddle –knee clearance & pedaling reach dimensions needs anthropometric data of buttock to knee length normal sitting, Foot length, Foot breath, Buttock to leg full external length, Buttock to length while raising on toe, Sit knee height. Based on the consideration of several data's shown in Table.3, the proposed design is framed using anthropometrics data dimensions as shown in Fig .9.

6.1 RULA analysis result validation

By undergoing RULA analysis using CATIA V5 the assessment score arrived 3 for the proposed design which is shown in Fig.13. Then final arriving score and which results as shown in Table. 4.

Fig.9. DHM Model in CATIA V5

Fig.10. Nee Clearance & Paddling Reach

Fig.11. Handle Reach

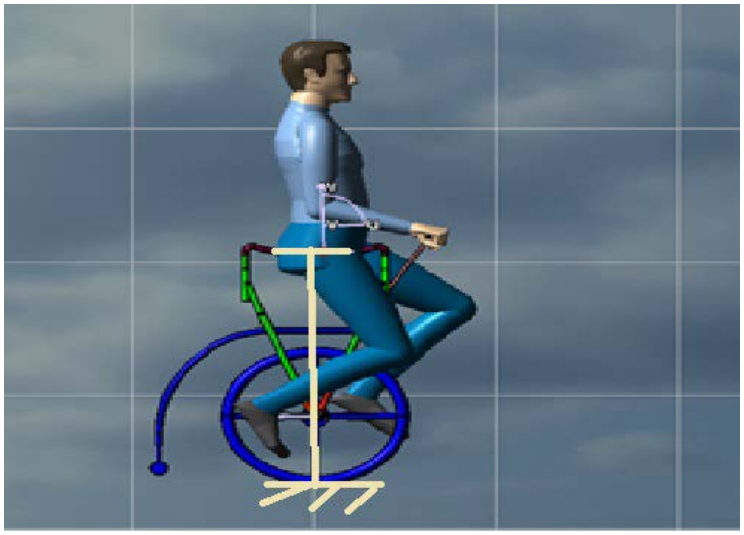


Fig.12.Height of Saddle (from Ground)

TABLE 4
PERCENTILE USED FOR CHECKING

Human Comfort	Indian Anthropometric Percentile	Adjustment Up to	Rapid Upper Limb Assessment (RULA) Score
Height of Saddle (from Ground)	5^{th}	95^{th}	3
Nee Clearance & Paddling Reach	5^{th}	95^{th}	
Handle Reach	5^{th}	95^{th}	

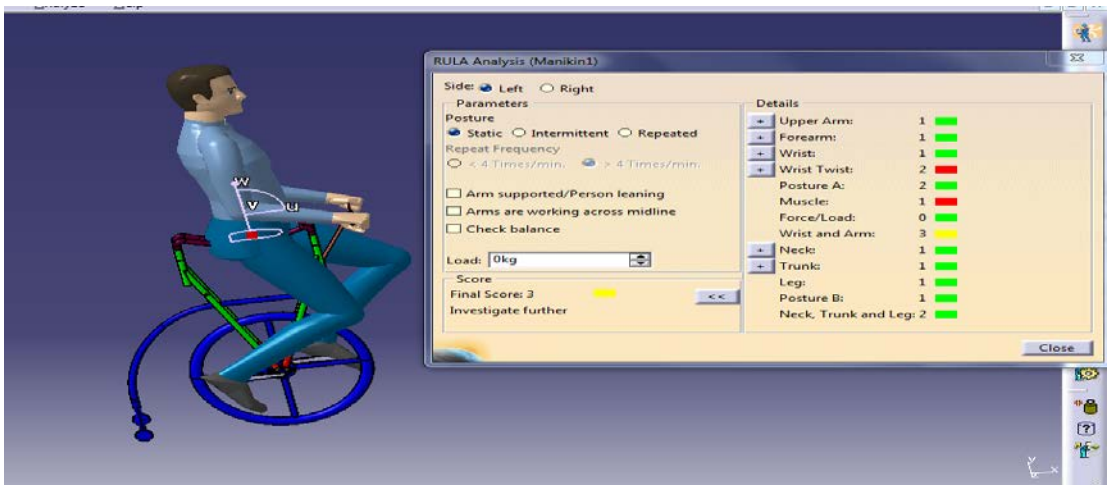


Fig.13.Rapid Upper Limb Assessment (RULA) Score

TABLE 3

MALE AND FEMALE INDIAN ANTHROPOMETRIC DATA USED FOR PROPOSED DESIGN

Name Of Parts Using Dimensions	Dimensions	Male and Female	Percentile 5th	50th	95th	Max
Frame Strength Design	Body weight	M	42	54	76	118
		F	40	53	74	88
Handle Bar Design	Hand length	M	163	180	191	229
		F	159	166	181	190
	Arm reach mid position length	M	749	849	939	1050
		F	704	799	919	980
	Hand Upper position length	M	469	629	799	940
		F	399	629	809	880
	Hand Lower position length	M	419	599	769	1030
		F	519	659	809	850
Saddle to Ground Height	Normal stand height	M	1529	1646	1751	1939
		F	1276	1504	1615	1681
	Buttock to leg full external length	M	971	1088	1209	1350
		F	910	999	1106	1230
Saddle-Knee-Pedal Reach Dimensions	Buttock to knee length normal sitting	M	489	558	615	861
		F	459	526	585	670
	Foot length	M	227	248	274	302
		F	207	227	249	283
	Foot breath	M	83	94	106	122
		F	75	84	96	114
	Buttock to leg full external length	M	971	1088	1209	1350
		F	910	999	1106	1230
	Buttock to length while raised on toe	M	569	659	769	960
		F	559	659	719	760
	Sit knee height	M	472	519	567	612
		F	440	489	520	578

Note: All datas
Length and Height in= mm
Weight in =kg

7 CONCLUSION

The concepts are generated focusing on the problems in the existing design. The generated concepts are evaluated

using Pugh chart. The Pugh chart proves to be a good concept selection tool in case of minimum information about the problem. The final concept selected using Pugh chart assures to be a cost effective design, satisfying the customer in terms of stability and safety. The ergonomic analysis is done in accordance with Indian anthropometric data using CATIA V5. It has provided the lower assessment score thus suggesting that the design is comfortable and effective then the previous design.

FUTURE WORK

In future, modelling details can be drawn out from ergonomic results followed by material selection, analysis & optimization. Once the design is optimized, the proposed design has to be fabricated.

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