AENSI Journals

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com

Conceptual Design for Multi Terrain Mobile Robot

[1]Chee Fai Tan, [3]T.L. Lim, [1]S.S.S. Ranjit, [1]K. Juffrizal, [1]M.Y. Nidzamuddin, [2]W. Chen, [2]G.W.M. Rauterberg, [1]S.N. Khalil, [1]D. Sivakumar, [1]E.S. Ng

[1]Integrated Design Research Group (IDeA), Centre of Advanced Research on Energy (CARE), Faculty of Mechanical Engineering, University Teknikal Malaysia Melaka, Melaka, Malaysia.
[2]Designed Intelligence Group, Department of Industrial Design, Eindhoven University of Technology, Eindhoven, the Netherlands.
[3]Intellogic Technology Pvt. Ltd, Puchong, Selangor, Malaysia.

ARTICLE INFO

Article history:
Received 12 October 2013
Received in revised form 14 November 2013
Accepted 20 November 2013
Available online 4 December2013

Keywords:
Total design conceptual design mobile robot

ABSTRACT

This paper presents the conceptual design of the multi terrain mobile robot with total design approach. Twenty conceptual designs were generated for selection purpose. To determine the final design of multi terrain mobile robot, the matrix evaluation method was used. The weight of the concept was obtained through weighted analysis. The final design of the multi terrain mobile robot is the mobile robot with six independent motorized wheels. The mobile robot has a steering wheel in the front and the rear, and two wheels arranged on a bogie on each side. Each wheel can operate separately on different type of terrain. Twenty conceptual designs were generated for selection. To determine the final design of multi terrain mobile robot, the matrix evaluation method was used. The weight of the concept was obtained through weight analysis.

To Cite This Article**:** Chee Fai Tan, T.L. Lim, S.S.S. Ranjit, K. Juffrizal, M.Y. Nidzamuddin, W. Chen, G.W.M. Rauterberg, S.N. Khalil, D. Sivakumar, E.S. Ng. Conceptual Design for Multi Terrain Mobile Robot**.** ***Aust. J. Basic & Appl. Sci., 7(12): 300-308, 2013***

INTRODUCTION

The application of mobile robot in our daily life has increased rapidly. Some of the applications of mobile robot are vacuum cleaning robot, military robot, grass cutting robot, surveillance robot etc. The mobile robotic technology has attracted the interest of academia and industries to develop multiple applications mobile robot. The demand of mobile robot for different type of new application is rising. The mobile robot is designed to travel on different type of environment either indoor or outdoor, or both. For outdoor, the mobile robot will operate on the road or off-road. The off-road type mobile robot requires special design of mechanism in order to be withstands any impact on different type of terrain. Different types of locomotion methods such as tracks, wheels and legs are used on outdoor type mobile robots.

Multi-terrain mobile robot can be in the form of a remote controlled or autonomous type. The Multi-terrain mobile robot can be equipped with sensors, camera, telecommunication instrument and other payloads. The developed multi terrain mobile robot is a prototype that will be tested in rain forest terrain for the surveillance and searching task. The mobile robot consists of a mobile, rigid chassis that can be equipped with functional heads for rain forest terrain and various maintenance tasks. Mobile robots are increasingly being used in hazardous, rough terrain situations, such as planetary exploration (Golombok, 1998). In search and rescue purposes, mobile robot can be used to move in the highly hazardous area. For the wheeled mobile robot, the study mainly is to focus on the method to reduce the slip. The reduction of wheel slip able to minimize the odometric error and energy consumption when operation. It will prolong the operation time of a mobile robot. Besides, the performance of a mobile robot will improve by good distribution of wheel speeds and torques (Hung *et al*., 2000; Iagnemma *et al*., 2002; Iagnemma *et al*., 2001; Iagnemma and Dubowsky, 2000; Cunningham *et al*., 1998; Osborn, 1989).

Moore *et al*. (2002) designed a hexapod mobile robot (RHex) with legs that can move in six degree of freedom. The robot can move on unstable ground and climb the stair. Siegwart *et al*. (2002) developed a 60cm by 20cm robot. The robot is design to climb an obstacle that higher that the robot and move on rough terrain.The Journey Robot is an outdoor robot designed to run off road in unstructured environments. It was inspired by the Defense Advanced Research Projects Agency (DARPA) Grand Challenge and built as a prototype vehicle for that competition.

Corresponding Author: Chee Fai Tan, Integrated Design Research Group (IDeA), Centre of Advanced Research on Energy (CARE), Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia.
E-mail: cheefai@utem.edu.my

Journey Robot is a fully autonomous, self-guided, mobile robot, capable of navigating on its own to an arbitrary set of waypoints while avoiding obstacles along the way (Anderson, 2006). Subsequently, an Omni-directional mobile robot is designed to move in multiple directions. With the track near-arbitrary motion ability, the robot is able to move fast in different type of terrain (Udengaard and Iagnemma, 2008). Carnegie and Cordes (2004) designed and constructed a low cost outdoor caterpillar-track robot. The maximum payload of this robot is 100kg and it is able to operate at least 1 hour. Besides, the robot is able to operate in different type of weather.

Design Methodology:

Mechanical design is the design of things and systems such as mechanical natural-machine, products, structures, devices and instrument. Mechanical design utilizes mathematics, the materials science, and the engineering-mechanics science. For the mechanical design of multi terrain mobile robot, the consideration of the design phase is the most important criteria, then followed by determine the design software which will be used in designing the structure and finally, mechanism design that determined the velocity and force.

The Phases of Design:

In the process of designing the high flexibility terrain rover, there are many step need to be concerned in order to make sure that the terrain rover able to achieve the goal of this thesis. The phase of design for this project include the target specification process, concept generation process, list of target specification, generated 20 concept of terrain rover and finally the part of concept selection which depends on the selection criteria that been set.

Target Specification process:

After the identifying problem statement, the product development follows by target specification (Tan *et al*, 2013a; Tan *et al*., 2013b). The target specification was established in the early stage of development process so that the product design can meet the target specification. There are a few steps to establish a target specification. Firstly, a list of metrics will be prepared. Then, the competitive benchmarking information will be collected. Next, the ideal and target values will be set. Lastly, the results and the process will be reflected.

A list of metrics:

On this step, the main process is gathering the metrics that reflect as directly as possible the degree to which the product satisfies the customer needs. A list of matrix that represents the user requirement was developed. Table 1 shown the list of metric for multi terrain mobile robot.

Table 1: List of Metric

No.	Metric	Weight	Units
1	The durable of the terrain rover.	5	*Newton*
2	Material of the bag body	5	*List*
3	Total mass	4	*Kg*
4	Wheel size	3	*List*
5	Unit manufacturing cost.	5	*RM*
6	Time to disassemble and assemble for maintenance.	3	*h*
7	Special tools required for maintenance	2	*List*
8	Total height and wide	3	*mm*

Competitive Benchmarking Information:

During this step, the main purpose is to collect the information about the existing products. Subsequently the product can compete in the marketplace. To get the information, a survey conducted to explore the market of mobile robot and locomotive. The survey not complete if only investigate the existing products. This is more important to know the user requirements of user. Observation about the taste of customer in the market was carry out by note down which type of locomotive is able solve the problem that occur.

Ideal And Target Values Setting:

After the related information has been collected, the information was synthesized for target values setting. The target values such as an idea value and a marginally acceptable value was input to the metrics. The values of metrics was express as follows:

- **At least X:** to establish the targets for the lower bound on a metric.
- The base of the terrain rover can at least withstand 25kg in weight, because the base can carry things like camera, controller and others.
- The wheels that use at least can withstand 5kg to avoid failure.
- **At most X**: to establish the targets for the upper bound on a metric.

- The body of the terrain rover at most 250 mm in height.
- The body of the terrain rover at most 100 mm in wide.
- The weight of the transporter at most 10 kg.
- **Between X and Y**: to establish both upper and lower bounds for the value of the metric.
- The terrain rover base can support a weight between 10 to 20 kg.
- **Exactly X**: to establish the target of a particular value of a metric, with any deviation degrading performance.
- The base of the transporter is exactly support a battery, and PCL controller.

Reflect On The Results And The Process:

During this process, the targets need to be agreeing iteration. Once the target has been set, these targets can guide the team to select a concept or solution concepts. The reflection also important to ensure that the metric that chose is correct and suitable. Reflect also know as a final step to conclude all the metric and specification that chosen.

Concept Generation Process:

The engineer will generate the conceptual ideas as input to the problem solving solutions (Tan *et al*., 2007; Tan *et al*., 2009; Tan *et al*., 2010). The concept generation process is iterative. Figure 1 present a five-step concept generation method where it breaks a complex problem into simpler sub problems.

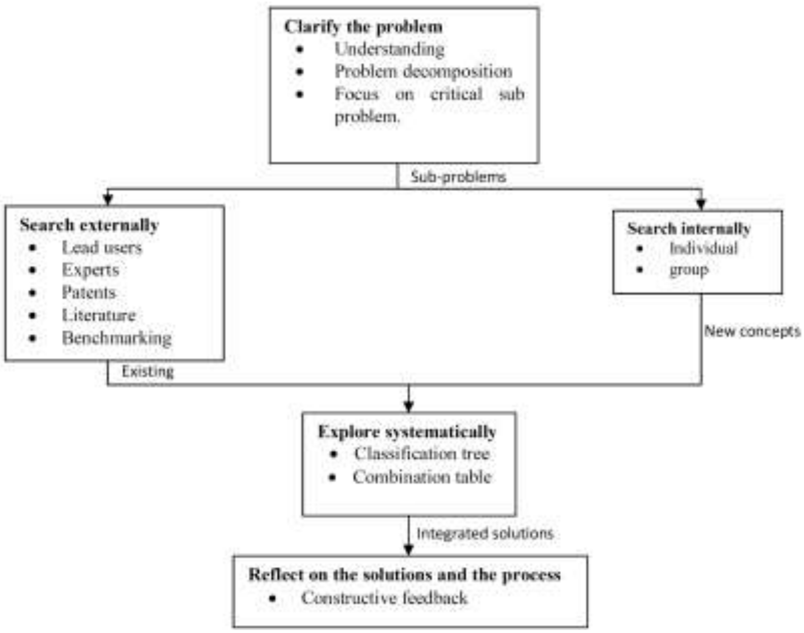


Fig. 1: Concept generation flow chart [22]

Step 1: Clarify the problem :

This is the first stage of concept generation. During this stage, the main activity is to justify the problem in order to break the problem into sub problems. Understanding the problem is very important because this will guide the designer to generate the concept depend on solving the problem. The problem can get from the user opinions, regulation and product constrain. This step also involves the process to break the problem into simpler sub problem. This is useful for a complex problem to be solved in a simpler form. The problem is decomposing into sub problem. Figure 2 shown decompose a complex problem of terrain rover.

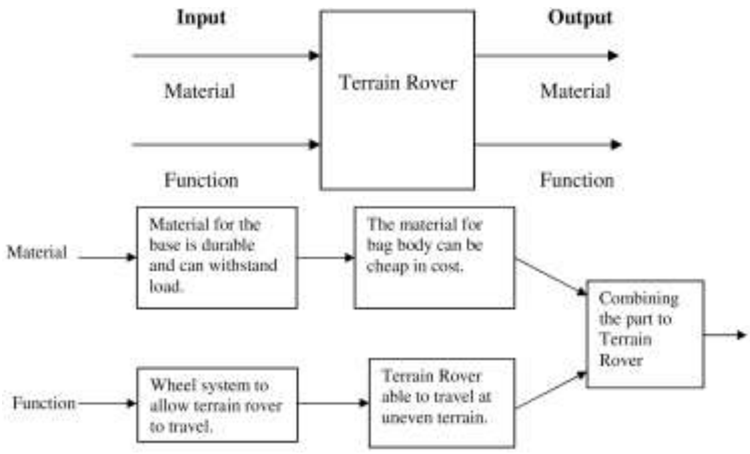


Fig. 2: Decompose a complex problem [22]

Step 2: Search Externally:

Next step is the activities that find the existing solutions to the overall problem and the sub problem that clarify in the clarifying step. This step is usually easier than create a new solution. There are a few ways to gather information from external sources:

- Consult experts—consult the experts to get the knowledge for the solution of general and sub problem. For example consult the lecturer.
- Search patents—searching the local and oversea patent to get the source of technical information. But the solution found is protected.
- Searches published literature—gather the information from journals, conference proceedings, trade magazines and government report.
- Benchmark related products.—study of the existing products with functionality similar to that product.

Step 3: Search Internally:

Search internally is the step that generating the solution concept by using personal and team knowledge and creativity. These activities can be carrying out by individual or group. There are a few guidelines that for improving both individual and group search:

- Suspend judgment: no criticism allow when generate a concept solution.
- Generate a lot of ideas: the more idea created the more precise the problem is solved.
- Welcome ideas that may seem infeasible: improve the infeasible idea that proposed.
- Use graphical and physical media: use the right things or media to produce the concept solution.

There are also some hints to generate the concept solutions

- Make analogies—make a biologically or natural analogy to the problem.
- Wish and wonder—ask these question when start to design a concept solution.
- Use related stimuli—the new idea can be generated by presented a related stimulus.
- Use unrelated stimuli—an unrelated stimulus also can help generating the idea.
- Set quantitative goal—set a quantity of idea concept that might be generated.
- Use the gallery method—use the gallery method to display a large number of concept idea for the solution.

Steps 4: Explore Systematically:

The following step is the results of the external and internal search activities. This step activities is to collect the concept idea for solution into a systematically method. By using this method, the concept solution can be observed clearly and make a decision and discussion.

There are a few method to generate the concept idea into a systematically form and different benefit.

- Concept classification tree
- Concept combination table
- Managing the exploration process

Australian Journal of Basic and Applied Sciences, 7(12) Oct 2013, Pages: 300-308

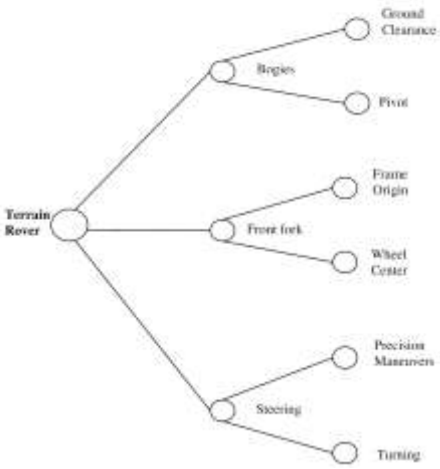


Fig. 3: Concept classification tree

Step 5: Reflect On The Results And The Process:

The last step in generating the concept solution is reflecting on the result and process. At this step, some question and meeting will be carry out to refine the concept solution and double checking the solution weather fulfill the customer need or problem. This step is an important step to conclude the entire concept generating process and give the comment and refinement to the concept solution.

List Of The Target Specification:

To set final specification is very important because this target specification is use as guideline to generate concept solution. This is the input for the concept generating. The concept generating is depend on the metric and constrains. There are a few steps to establish the final target specification as follows:

- Develop a technical models
- Develop a cost model
- Refine a specification
- Break down specifications
- Reflect on the results

Table 2 shown of target specification of terrain rover.

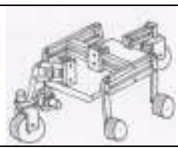
Table 2: List of Target Specification

No.	Metric	Weight	Units	Marginal Value	Ideal Value
1	The durable of the terrain rover.	5	Newton	> 1000N	1200N
2	Material of the terrain rover.	5	List	Al, Delrin	Al, Delrin
3	Total mass	4	Kg	< 10Kg	< 6Kg
4	Wheel size	3	List	< 8mm(ø)	< 16mm(ø)
5	Unit manufacturing cost.	5	RM	< RM1500	< RM1000
6	Time to disassemble and assemble.	3	h	<3 h	<2 h
7	Special tools required for maintenance	2	List	Allen keys	Allen keys
8	Total height and wide.	3	mm	< 220 X 650mm	< 230 X 600mm

Conceptual Design:

After concept generation and target specification had done, concept of terrain rover had been generated. Table 3 and Table 4 present 20 concepts of terrain rover:

Table 3: 20 Terrain Rover Concepts

Concept		Description
Concept 1:		This concept is a six motorized wheels. Five wheels are able to move flexible based on the terrain condition and one wheel is attached rigidly to the main body.

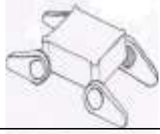
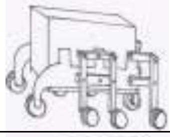
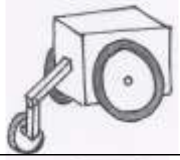
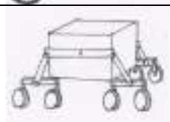
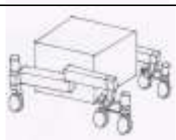
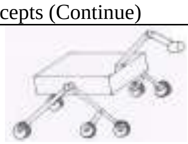
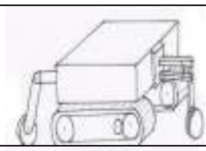
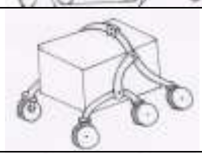
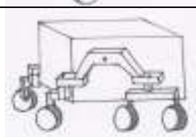
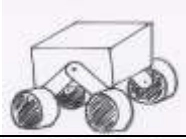
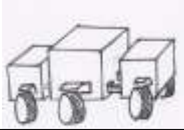
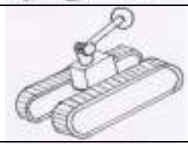
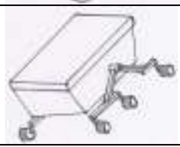
Concept 2:		The mobile robot has 4 powered wheels as shown. Each wheels control by it owns motor. Either side of 2 wheeled bogies have stable base.
Concept 3:		This robot has 4 track wheels with two degree of freedom. Each wheel and track able to move separately. This type of robot able to rotate continuously 360º freely, good in stair climbing and overcome different type of obstacle.
Concept 4:		This rover consists of four wheels. Each wheel can move independently.
Concept 5:		This terrain rover is a six-wheeled spring less suspension system. Each pair of wheel has a rocker arm and secondary arm.
Concept 6:		This concept has two fixed wheels in front and two set of bogies at both side.
Concept 7:		This concept is designed with front bogie and two fixed wheels at both sides. The concept able made the robot to avoid obstacles by jumping mechanism.
Concept 8:		The concept of this rover is driven by 8 wheels. Main purpose is to add the stability of the rover while clamping.
Concept 9:		This rover is built to explore an unknown environment. The front and the real are independently steer. The motor will mount at the top of the front and real wheel.
Concept 10:		The concept of this terrain rover has only a driving unit and four legs to support it. This rover act like animal. Each wheel control by each motor. Front wheel controlling the direction and real wheel controlling forward and backward.

Table 4: 20 Terrain Rover Concepts (Continue)

Concept 11:		This concept of rover has six motorized wheels that is mounted on a rocker-bogie articulated frame.
Concept 12:		The mobile robot has two powered wheels and two tracks which each track will control the movement by two cogwheels. Two motor used to control each of the wheel, others two use to control the cogwheel at track. There have two tracks at this terrain rover. Four cogwheels use to drive the two tracks at left and right hand side.
Concept 13:		This rover concept has six independently wheels mounted on rover articulated frame.
Concept 14:		The designed rover is built to explore an unknown environment. It is driven by six wheels where front wheel is controlling the direction. Each wheel will control by its own motor which mount on the wheel.

Concept 15:		The concept of this rover has only a driving unit and four legs to support it. Each wheels control by its' own motor. The front wheel is controlling the direction of rover, however the rear wheels is controlling the movement of rover to move forward or backward.
Concept 16:		The concept of this mobile robot has six powered wheels as shown. Each wheels control by it owns motor. In the front and middle wheels are articulated by parallel linkage. Either side 2-wheeled bogies provide lateral stability.
Concept 17:		The designed rover is driven by 5 wheels which can be controlled independently.
Concept 18:		This is based on a '3-segment' design which allowed each segment in dependent movement. This enables the rover to traverse uneven terrain while having all wheels in contact with the ground.
Concept 19:		This rover consists of two tracks and an arm.
Concept 20:		This rover has six independently wheels mounted in a rocker-bogie articulated frame. Each pair of wheel consists of a main rocker arm and secondary arm.

Concept Selection:

Concept selection is based on the customer and other criteria as input to select the optimum concept. The technique compares the strength and weaknesses of the concept, then select one or more concepts for further action.

Concept-Screening Matrix:

This matrix was created and used to design the terrain rover. The purposes of this stage are to narrow the number of concepts quickly. Table 4 presents concept screening matrix.

Table 4: Concept-Screening Matrix

	Concepts																			
Selection Criteria	**1**	**2**	**3**	**4**	**5 (R)**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15 (R)**	**16**	**17**	**18**	**19**	**20**
Functionality																				
Lightweight	0	+	0	0	0	-	+	0	0	+	-	-	0	-	0	-	-	0	-	-
Moveable	+	-	0	0	0	+	-	0	0	-	0	+	+	+	0	+	+	+	-	0
Capacity	0	+	0	-	0	-	0	+	+	-	+	+	+	+	0	+	+	-	-	+
Convenience																				
Multipurpose	+	0	0	0	0	+	-	0	0	-	+	+	+	+	0	+	+	0	-	+
Convenience of storing	+	-	+	0	0	+	-	+	0	-	+	0	0	0	0	+	0	-	-	0
Portable	0	+	0	-	0	-	+	0	-	+	-	-	-	-	0	-	-	0	-	0
Easy to maintain and repair	+	0	-	0	0	+	+	0	0	-	+	-	-	0	0	0	-	0	-	0
Ergonomics																				
Easy to handling the Terrain rover	-	+	-	0	0	-	+	0	-	+	+	-	+	-	0	0	-	0	0	0
User friendly	+	0	-	-	0	-	-	+	-	+	+	-	+	0	0	+	-	+	-	-
Suitable for average Material Size	-	0	+	+	0	0	-	0	0	-	+	+	+	+	0	+	+	0	-	+
Durability																				
Longevity	+	0	-	0	0	+	+	0	-	-	0	-	0	0	0	0	-	0	+	0
Work reliably	0	0	+	0	0	0	-	0	0	+	0	+	0	0	0	0	-	0	+	+
Cost materials	0	+	-	0	0	-	+	0	0	+	0	-	-	0	0	0	-	0	+	+
Manufacturability	0	-	+	0	0	+	0	-	+	-	0	-	-	0	0	0	-	0	-	0
Sum +'s	6	5	4	1	0	7	6	2	2	6	7	5	6	4	0	6	4	2	3	5
Sum 0's	6	6	5	10	14	2	2	10	8	0	5	1	4	7	13	6	1	10	1	7
Sum -'s	2	3	5	3	0	4	6	2	4	8	2	8	4	3	0	2	9	2	10	2
Net score	4	3	-1	-2	0	3	0	0	-2	-2	5	-3	2	1	0	4	-5	0	-7	-5
Rank	1	3	7	9	6	2	4	5	8	10	1	7	3	4	5	2	9	6	10	8
Continue?	Yes	Yes	No	No	No	Yes	No	No	No	No	Yes	No	Yes	No	No	Yes	No	No	No	No

Base on the concept screening matrix shown about, the selected concepts are concept 1, concept 2, concept 6, concept 11 and concept 13. Having determined the concepts for further analysis, clarification of which issues need to be investigated further before a final selection can be made. The concept scoring stage with its weighted selection criteria and more detailed rating scheme would be done as present at next page.

Concept - Scoring Matrix:

Concept scoring is used when the user want to select the optimum solution of the concept. A weight is defined and each criterion was compared. It determine by the weighted sum of the rating as shown in Table 5.

Table 5: Concept-Scoring Matrix

Selection Criteria	Weight	R	W/S	R	W/S	R	W/S	R	W/S	R	W/S
Functionality	20										
Lightweight	5	5	25	8	40	8	40	6	30	5	25
Moveable	5	6	30	4	20	3	15	4	20	5	25
Capacity	10	5	50	5	50	4	40	3	30	5	50
Convenience	30										
Multipurpose	10	8	80	6	60	3	30	4	40	5	50
Convenience of storing	5	6	30	7	35	2	10	6	30	5	25
Portable	10	4	40	4	40	4	40	5	50	5	50
Easy to maintain and repair.	5	8	40	8	40	5	35	4	20	5	25
Ergonomics	20										
Easy to handling the Terrain rover	10	7	70	3	30	6	60	7	70	6	60
User friendly	5	8	40	5	25	4	20	7	35	6	30
Suitable for average Material Size	5	6	30	2	10	5	25	8	40	6	30
Durability	20										
Longevity	10	8	80	4	40	2	20	5	50	6	60
Work reliably	10	7	70	6	60	3	30	7	70	8	80
Cost of raw materials	5	6	30	1	5	5	25	6	30	5	25
Manufacturability	5	8	32	6	30	6	30	8	40	5	25
Total Score			647		485		420		555		560
Rank			1		4		5		3		2
Continue?			Yes		No		No		No		No

From the total weight score shown about, concept 1 gains the highest score from this ranking. Thus, concept 1 was promising and would be likely to result in a successful product.

Conclusion:

There were twenty conceptual designs were developed with total design approach. The total design process is used as a guideline to develop the conceptual design. After the development of conceptual design, the weighted objective was used to identify the most suitable design for this project. Concept 1 is chosen as the best design among concepts. The final multi terrain robot is equipped with front and side motorized bogies in order to overcome the different type of terrain. The result from this research work is useful in the future development of multi terrain mobile robot.

ACKNOWLEDGEMENT

The authors / researchers are very much in-debt to thank the top level management of Universiti Teknikal Malaysia Melaka (UTeM), including Centre for Research and Innovation Management (CRIM) and Faculty of Mechanical Engineering administrators which enabled the progressing of this development.

REFERENCES

Anderson, D.P. and M. Hamilton, 2006. The Journey Robot. Dallas Personal Robotics Group.

Carnegie, D.A. and J.C. Cordes, 2004. The Mechanical Design and Construction of a Mobile Outdoor Multi-Terrain Robot. Proceedings of Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 218: 1563-1575.

Cunningham, J., J. Roberts, P. Corke and H. Durrant-Whyte, 1998. Automation of Underground LHD and Truck Haulag. In Proceedings of Australian IMM Annual Conference, pp: 241-246.

Golombek, M., 1998. Mars Pathfinder Mission and Science Results. Proceedings of the 29th Lunar and Planetary Science Conference.

Hung, M.H., D.E. Orin and K.J. Waldron, 2000. Efficient Formulation of the Force Distribution Equations for General Tree-Structured Robotic Mechanisms with a Mobile Base. IEEETransactions on Systems, man and Cybernetics, Part B: Cybernetics, 30(4): 529-538.

Iagnemma, K., D. Golda, M. Spenko and S. Dubowsky, 2002. Experimental Study of High-Speed Rough-Terrain Mobile Robot Models for Reactive Behaviors. In Proceedings of the 8th InternationalSymposium on Experimental Robotics, Sant'Angelo d'Ischia, Italy.

Iagnemma, K., H. Shibly, A. Rzepniewski and S. Dubowsky, 2001. Planning and Control Algorithms for Enhanced Rough-Terrain Vehicle Mobility. In Proceedings of the Sixth International Symposium on Artificial Intelligence, Robotics and Automation in Space. Saint-Hubert, Quebec.

Iagnemma, K., H. Shibley and S. Dubowsky, 2002. On-Line Terrain Parameter Estimation for Planetary Vehicles. In Proceedings of 2002IEEE International Conference on Robotics and Automation (ICRA2002). Washington D.C., pp: 3142-3147.

Iagnemma, K., and S. Dubowsky, 2000. Vehicle Wheel-Ground Contact Angle Estimation: with Application to Mobile Robot Traction Control. In Proceeding of 7th International Symposium on Advances in Robot Kinematics. Piran, Slovenia, pp: 137-146.

Moore, E.Z., D. Campbell, F. Grimminger and M. Buehler, 2002. Reliable Stair Climbing in the Simple Hexapod 'RHex'. In Proceeding 2002 IEEE International Conference on Robotics and Automation, pp: 2222-2227.

Osborn, J.F., 1989. Applications of Robotics in Hazardous Waste Management. In Proceedings of the SME 1989 World Conference on Robotics Research. Gaithersburg, Maryland.

Siegwart, R., P. Lamon, T. Estier, M. Lauria and R. Piguet, 2002. Innovative design for Wheeled Locomotion in Rough Terrain. Robotics and Autonomous Systems, 40p: 151-162.

Udengaard, M., and K. Iagnemma, 2008. Design of an Omnidirectional Mobile Robot for Rough Terrain. In Proceedings of the 2008 IEEE International Conference on Robotics and Automation.

Tan, C.F., V.K. Kher and S.S.S. Ranjit, 2013a. An Interactive System for Concurrent Engineering Design. Applied Mechanics and Materials, 313-314: 990-994.

Tan, C.F., W. Chen and G.W.M. Rauterberg, 2013b. Total design of active neck support system for economy class aircraft seat. Applied Mechanics and Materials, 372: 657-660.

Tan, C.F., F. Delbressine and G.W.M. Rauterberg, 2007. Vehicle seat design: state of the art and recent development. Proceedings of 3rd World Engineering Congress, pp: 51-61.

Tan, C.F., W. Chen and G.W.M. Rauterberg, 2009. Design of aircraft cabin testbed for stress free air travel experiment. 5th International Conference on Planning and Design, p: 157.

Tan, C.F., W. Chen and G.W.M. Rauterberg, 2010. Total design of low cost aircraft cabin simulator. Proceedings of Design., pp: 1721-17280.