A FRAMEWORK OF UT-UTEM MOBILITY PROGRAM BASED ONDIGITAL ENGINEERING AND DETERMINISTIC DESIGN

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ABSTRACT: The University of Tokushima (UT) and Universiti Teknikal Malaysia Melaka (UTeM) have concluded an academic partnership under the academic agreement of MOU/MOA in 2013. As one of the joint activities for the agreement, a mobility program was initiated as MMPT2013 and the mobility students of UTeM joined the CEL Summer Program (CELSP) at UT in 2013. This paper presents the framework of CELSP based on an approach of digital engineering and deterministic design. The idea of this approach was derived from SCW project based on the historical design of a stair-climbing wheelchair. The design was made before the proposal of deterministic design and even before the birth of computer-aided design software (CAD), or one of the very popular digital design tools today. Reviewing SCW project from deterministic design point of view using a digital engineering approach, this paper overviews CELSP and shows how this approach was applied to one of the sessions of CELSP.

KEYWORDS: *Deterministic Design, Digital Engineering, Computer-Aided Design, Wheelchair Design.*

1.0 INTRODUCTION

The University of Tokushima (UT) and Universiti Teknikal Malaysia Melaka (UTeM) have concluded an academic partnership under the academic agreement of MOU/MOA in 2013. As one of the joint activities for the agreement, a mobility program was initiated as MMPT2013 (UTeM Mobility Program at UT) and the mobility students of UTeM joined the CEL (Collaborative Engineering Laboratory) Summer Program (CELSP) at UT in 2013 [3]. CELSP is derived from SCW project, which is a digital engineering project for an undergraduate student at

UT based on a historical design of a stair-climbing wheelchair. The project conducted a design review on the historical design using a solid CAD model of wheelchair, in which process deterministic design review was also conducted. The project lead a successful achievement of the student, since the basic digital engineering and deterministic design thinking lessons were well included in the project. As for CELSP, the program period is only one month, during which several activities are included, such as cultural, academic, laboratory, and robotics exposures. Therefore, a deterministic design framework derived from SCW project was proposed and applied to the robotics session of CELSP.

First, this paper overviews SCW project and shows the framework based on digital engineering and deterministic design used in SCW project. Overviewing CELSP2013 in MMPT, this paper presents a deterministic design framework derived from SCW framework and discusses the feasibility of the framework for future collaboration of UT-UTeM.

2.0 STAIR-CLIMBING WHEELCHAIR PROJECT

The historical CAD system called SKETCHPAD at MIT by Ivan Sutherland in 1963 is the beginning of CAD system [6]. The distinctive feature of SKETCHPAD was that it allowed the designer to interact with his computer graphically: the design can be fed into the computer by drawing on a CRT monitor with a light pen. It was a prototype of graphical user interface, an indispensable feature of modern CAD system. Figure 1 shows the overview history of 2D/3D CAD systems, which was started in 1960 and is still under development towards new technologies. After 50 years of technical evolution of CAD idea, digital engineering tools are very popular today and it would be almost impossible to design new products without these tools [1].

When one of the author was involved in the design class MIT a few years ago, digital engineering tools were already very common for teaching design thinking and its implementation; for example, computer-aided design software such as Solidworks for design the idea of students, computer-aided analysis tool such as Matlab for analyze the proposed design, and computer-aided machine tools such as CNC milling machines for manufacturing the design. Under these circumstances, the author was very much impressed by the traditional approach of [2], who teaches the elements of mechanical design and design thinking for the students. The inventions include biomedical devices, solar devices, aids for the handicapped, industrial systems, textile systems, and a stair-climbing wheel chair [2]. The stair-climbing wheelchair was designed in 1962 and its 1/4 scale model was built to test the design around that time [2]. According to the inventor of the week archive at MIT, the model had a set of retractable, spring-loaded spokes that could extend beyond the wheel rim to function as pinions, keeping the chair upright as it was powered up the stairs. The design was full of ideas, which were made before the invention of Sketchpad. Even though the design of wheelchair was tested feasible by the 1/4 scale model, digital engineering study was not made. The objective of SCW project was to make a digital model of the stair-climbing wheelchair based on the original mechanical sketch and to review the design and the feasibility of the idea by a digital engineering approach.

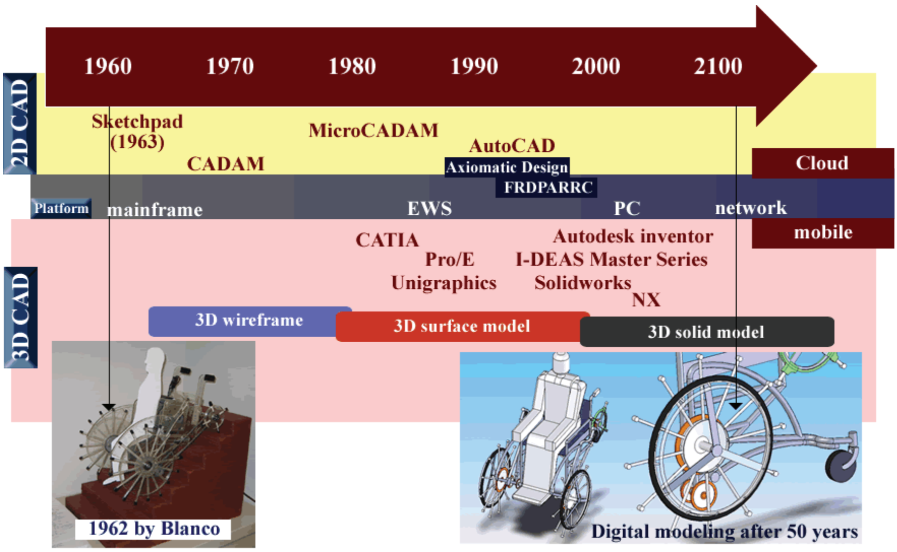

Figure 1: A brief history of 2D/3D CAD/CAM system

3.0 HISTORICAL DESIGN OF A STAIR CLIMBING WHEELCHAIR

The historical design of a stair-climbing wheelchair was studied based on the task requirements below ranging from T1 to T11 and was proposed as shown in Figure 2. The design was created based on the creative design thinking all the way back in 1960's, which was 30 years before the axiomatic design methodology. A 1/4 scale model was fabricated at that time based on this mechanical drawing in order to review the feasibility of stair-climbing capability. Referring to this design, SCW project built a digital model to review the design and to analyze the feasibility.

T1. A stair climbing wheelchair that enables a patient to move around and up or down in a public or private building without the user requiring any external help.
T2. The wheelchair should operate equally well on any type of stairs of reasonable width. (No less than 32″ (81.3cm))
T3. The chair should fold easily and should have a folded width less than 7″ (17.8cm) in excess of the light standard people.
T4. The safety of the chair should not be endangered even if he/she uses or operates elements of the device improperly.
T5. The total weight of the chair should not exceed that of conventional battery driven models (80lbs. (36.29kgs) without batteries)
T6. The operation of the chair when climbing should be performed by no more than two hand controls.
T7. The chair should be operated by using trunk and arm muscles without external power.
T8. The physical appearance of the chair should resemble as closely as possible that of conventional models.
T9. The chair should be able to operate satisfactorily with a 200 lbs. (90.72kgs) occupant.
T10. Muscular effort needed for climbing should be below 25 lb. (11.34kgs) per arm.
T11. Retail price of the chair should be less than $200.00.

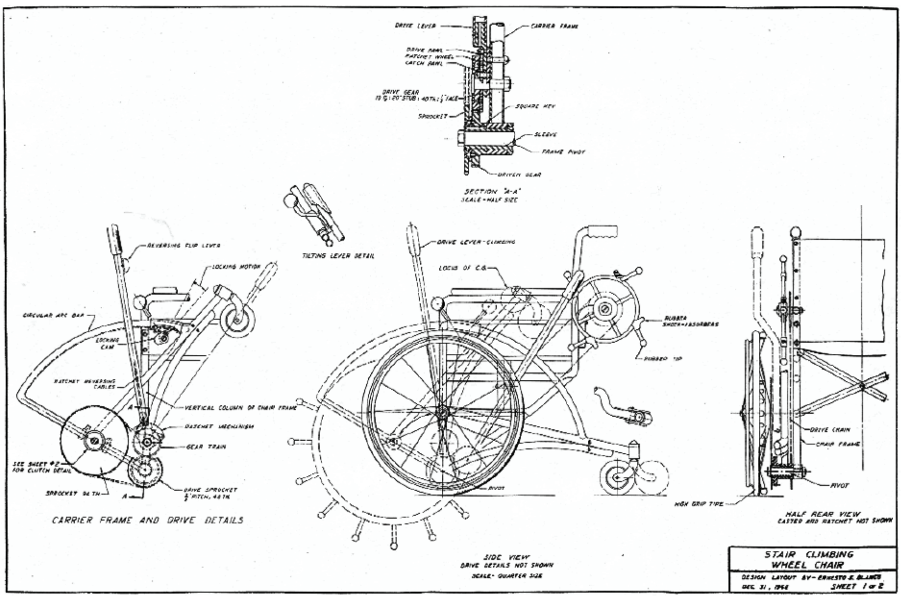

Figure 2: Original mechanical drawing of stair-climbing wheelchair

4.0 DETERMINICS DESIGN AND SOLID MODELING OF A STAIR CLIMBING WHEELCHAIR

Everything happens for a reason, so does design. The deterministic design is derived from the axiomatic design in 1990 [8], and is followed by FRDPARRC in 1992 as shown in Figure 3 [7]. Designers focus on available resources and apply them to their design in order to discover and to understand the issues that would otherwise lead to uncertainty. Minimizing uncertainty, and hence risk, makes a design more deterministic. Good design practice indicates that there is a minimum set of issues to be addressed: The functions a design must perform are the Functional Requirements (FR). The means by which the functions can be accomplished are the Design Parameters (DP). Analysis (A) is often required to develop the FRs and DPs. References (R) are often consulted. Risks (R) associated with each FR and DP must be identified. For each risk, countermeasures (C) must be thought of ahead of time. Combining all of these items, Figure 3 shows FRDPARRC table to guide the deterministic design. Even though this table was not proposed at the time of the wheelchair design, the design process was well matched to the table. Using a CAD solid model based on the original drawing, the design process was made clear in SCW project.

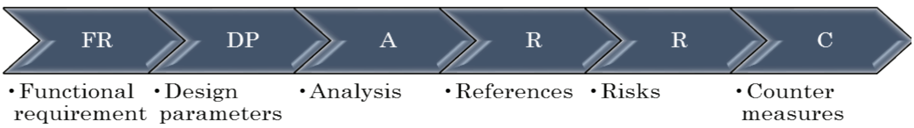

Figure 3: FRDPARRC table for deterministic design

Referring to the original design described in Figure 2 of the previous section, a CAD solid model was designed and built for SCW project. For analytical purposes, the design was given some minor modifications to make it simpler as shown in Figure 4. The model was built by assembly of basic components including body frame, seat, main wheel, sub-wheel, lever, and climbing unit. The number of all parts is 38, from which 18 subassembly are made in this model.

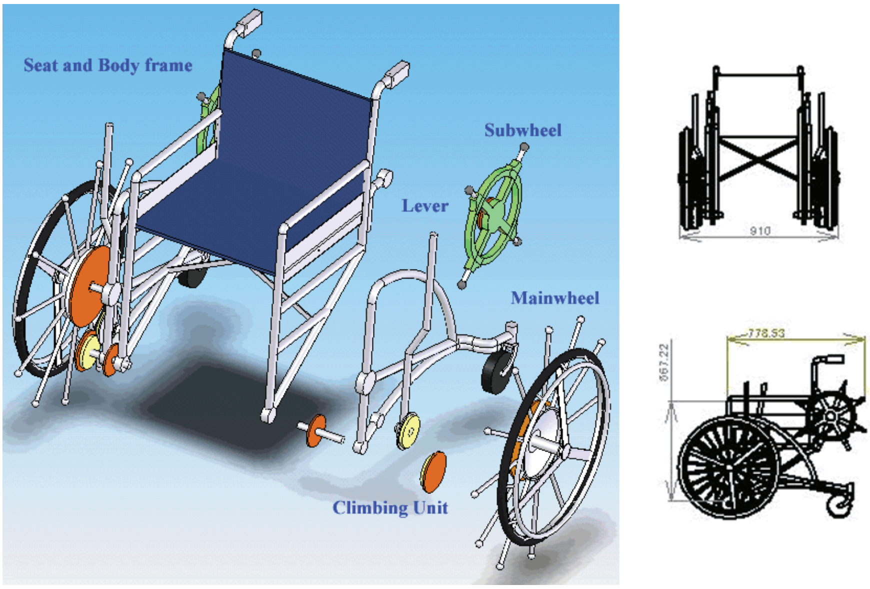

Figure 4: Digital model of the stair-climbing wheelchair based on the original drawing

Here are some confirmations regarding the fulfillment of task specification for the design. The size requirement in T2 is satisfied obviously as mentioned in Figure 4. The folding size requirement in T3 is also satisfied. The physical appearance of the wheelchair in Figure 4 resembles as conventional models, which satisfies the requirement task T8. These requirements were of course all clear in the original drawing. However, the CAD solid model built in SCW project could apparently show the evidence in a digital engineering manner.

5.0 DIGITAL ENGINEERING ANALYSIS

The CAD solid model not only provides the 3D shape of the design for design review as mentioned in the previous section, but also digital engineering analysis for more detailed design review using simulation tools [4].

The whole weight of the wheelchair is calculated as 23.6 Kg based on the calculation of CAD solid model with appropriate materials for the design, which satisfies T5. Balance conditions were studied using the total weight of 100.49 Kg with a human subject. If the materials or the human subject conditions are modified, the updated results would automatically generated. This section covers some of the analysis results obtained from SCW project.

5.1 Feasibility of Stair-Climbing Analysis

Feasibility of stair-climb ability was proved true using a 1/4 scale model based on the original design in 1962. The original model had a set of retractable, spring-loaded spokes that could extend beyond the wheel rim to function as pinions, keeping the chair upright as it was powered up the stairs. It was tested using the 1/4 scale model that moves using an electric motor and found that it could, in fact, climb stairs. This section shows the feasibility analysis by a digital engineering approach using the CAD solid model. To climb up the stairs, the main wheel of the wheelchair is rotated by the handle lever. Based on the lever length, gear reduction ration, and mechanical loss, the shaft torque is calculated as 68-103 Nm for main wheel and 34-51 Nm for sub-wheel as shown in Figure 5.

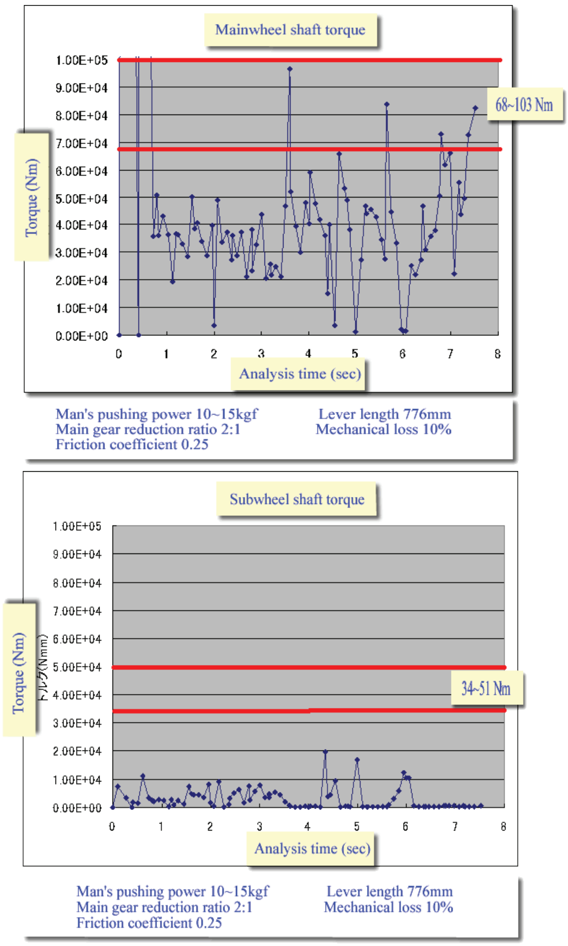

Figure 5: Main/sub-wheel shaft torque calculation based on the CAD solid model

Considering the average pushing power of human is 98-104N (10-15Kg), which corresponds to the task specification T10 of 25 lb. (11.34kgs) per arm, it was confirmed that the wheelchair of 100.49 Kg can be climbing up the stairs with the human power, which satisfies the task requirement T9. Climbing down the stairs can also be feasible since the required pushing power is less.

6.0 STUDY OF STAIR-CLIMBING BALANCE

To climb up or down stairs safely, stair-climbing balance was studied using the CAD solid mode. According to the calculation, the safety tilt angle of the wheelchair is 29-32 degree from vertical axis or more flat. The safety angle of the staircase is 34-51 degree, with the step size of 280mm depth and 180mm height. The stair-climbing down simulation showed the feasibility of the balance on condition that the wheelchair is kept within these safety angles. Figure 4 shows the outline of safety angles obtained from the simulation, and time series variation of counter force and shaft torque. The results in section 5-1 and 5-2 support the feasibility of the original design to stair-climbing by a human subject.

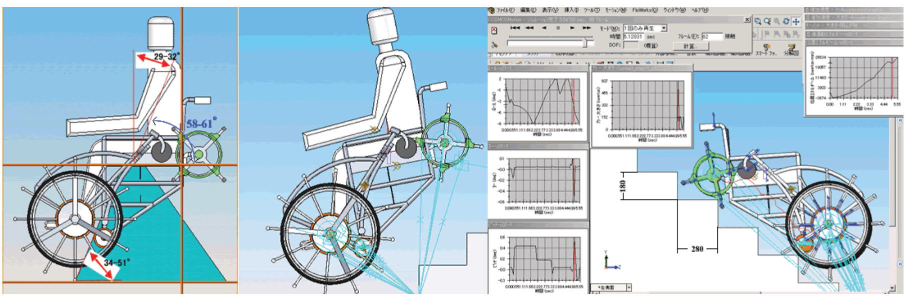

Figure 6: Stair-climbing balance analysis using a CAD solid model of the stair-climbing wheelchair

7.0 SAFETY ANALYSIS FOR STAIR-CLIMBING UP OR DOWN

Several accident scenarios possibly occurred under certain conditions were also studied using the CAD solid model. The previous section proved that this model can climb up/down the stairs. However, a falling down accident might happen under some conditions, for example, steep steps, thin surface of footsteps, slippery steps, over-speed run, etc. Figure 7 shows the three types of possible accidents in simulation; fall-out-of-the-step falling down, Jack knife falling down, and Wheelie falling down.

It shows that a fall-out-of-the-step accident happens when the sub-wheels at the back of the wheelchair ran off the steps due to some of the above mentioned reasons.

Figure 7: Safety analysis using a CAD solid model of the stair-climbing wheelchair

8.0 COUNTER MEASURES TO KEEP SAFETY IN STAIR-CLIMBING OPERATION

Stair-climbing down simulations were conducted in different scenarios based on the different parameters for different coefficient of friction values. To avoid falling down accidents, several ideas of counter measures were proposed and studied. For example, contact friction at the contact point on the step surface can be improved by some counter measures; different materials on the step surface, different types of contact point, etc. As opposed to the original spoke-end with cube type, the two types of spoke-end were proposed and reviewed. Figure 8 shows a cylinder-end type spokes and a pivot-end type spokes.

Figure 8: Counter measures using a CAD solid model of the stair-climbing wheelchair

9.0 CELSP 2013 AND DETERMNISTIC DESIGN LESSON USING SUMOBOT COMPETITION

UT has accepted exchange students/researchers from UTeM under irregular basis. The mobility program proposed by UTeM means not only the initial step for UT/UTeM collaboration for MOU/MOA, but also a candidate activity which both UT/UTM would like to continue on a regular basis. Discussing the time, duration, contents of the program, UT arranged a summer program called *Collaborative Engineering Laboratory Summer Program 2013 (CELSP2013)* as shown in Figure 9. Considering the successful result of SCW project, a deterministic design framework was applied to the robotics session of CELSP2013.

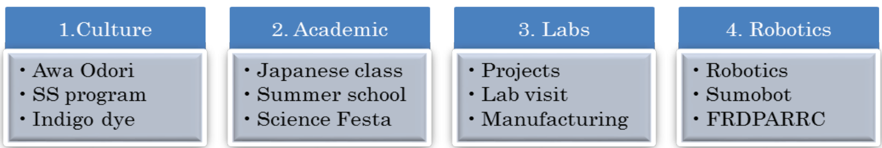

Figure 9: Overview of Collaborative Engineering Laboratory Summer Program (CELSP) 2013

Figure 9 shows the overview of CELSP 2013 program including the four exposure sessions, which are culture, academic, labs and robotics. Tokushima is world-widely famous for its traditional dance festival called *Awa Odori Dance Festival* in the middle of August. The regular population of Tokushima city ca.300,000 increases to more than 1 million during the festival period between August 12-15 every year because of the attendee to the festival from all over Japan. The main part of cultural exposure session was focused on this festival. The four MMPT students attending the program were all Malaysia local and have never been abroad. Therefore, various types of visiting tour around Tokushima were also arranged as a cultural exposure experience, which includes Indigo dyeing experience, *Hyotanjima* cruise tour, *Naruto whirlpools* visit, *Disaster prevention center* visit, and many more.

UT opens *Summer School Program* every year to accept more than 30 international students for two types of topics. One is nanotechnology and the other one is materials science and electrical engineering and information science course. The lectures are conducted in English, not only by the lecturers but also by the graduate students themselves. Both international and local graduate students attend this short course so that participants are able to interact with people from different countries during the class. The four MMPT students attended the electrical engineering and information science course.

Lab exposure session was composed of two sub-sessions. One was lab tours to visit several research labs to observe research projects at UT, and the other one was an assignment of a small manufacturing project. As for the manufacturing project, a welding project was arranged for the four MMTP students. The assignment was to fabricate a triangular paperweight using steel rods under the support of the technical staff of UT.

Figure 10: Activity photos of CELSP 2013

Robotics exposure session started with Boe-Bot programming course [5] so that MMPT students can learn not only the robotics basics but also some application of robotics technology. This session was composed of two parts. The first half was Boe-Bot robotics basics and the second half was Sumo-bot competition. The first half of the session was based on a series of Boe-Bot projects, including introduction of microprocessor, servo motors, robotics navigation, tactile navigation with wiskers, light sensitive navigation with photo resisters, navigation with IR lights, and robot control with distance detection. All of these projects provided the training of programming skill using Basic stamps for microprocessor.

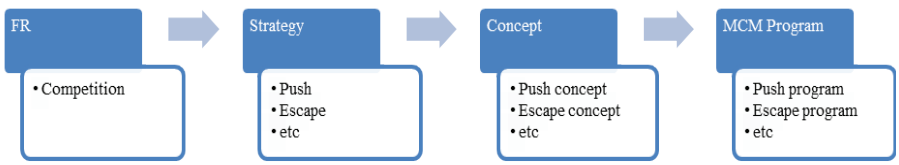

Figure 11: Deterministic design approach to SUMOTOB competition

The second half of the exercise was scheduled towards Sumo-Bot competition in CE lab. The challenge in this competition is to find the opponent and push it out of the flat ring, which is called *Dohyo*. The target of this exercise is to learn how to control a Sumo-Bot based on the lessons learned in the first half and to implement a control program to win the Sumo-Bot competition. In order to win the competition, just controlling the Sumo-Bot to move around is not sufficient. Tactics, strategy, and its implementation are all needed to be considered. The deterministic design framework for CELSP shown in Figure 11 was used in this exposure session.

The four MMPT students were divided into two teams of two students each. Each team worked on the deterministic design approach to implement a control program. The functional requirement is obviously to win the competition. The deterministic design thinking starts with the discussion on which strategy of competition, for example, *push forward strategy* in which the robot directly moves towards the opponent and push it out of the ring, *push behind strategy* in which the robot moves towards the backside of the opponent and push it from behind, *escape strategy* in which the robot just simply goes away from the opponent until the opponent goes out of the ring by itself, etc.

Once the strategy is determined, several candidate concepts to conduct the strategy are discussed in the team. In *push behind strategy*, for example, an idea would be a diagonal move shortly after the start signal, a left turn and move twice, and a push the opponent from behind. One of the candidate concepts is selected as the team concept. Then the most critical module (MCM) for the concept is determined to implement it as a control program of the robot. If the MCM program is implemented, the remaining portion of the concept can be implemented using a typical programming skill.

The SUMOBOT competition was conducted based on the standard SUMOBOT rule and the two teams of MMPT students enjoyed the competition, of which details has been reported [3]. The MMPT students learned the basic idea of deterministic design thinking, which is basically a design method but can also be applied to various engineering field including the development of robot control program in the SUMOBOT competition.

10.0 CONCLUSION

This paper presented the framework of UT-UTeM mobility program based on an approach of digital engineering and deterministic design. An example of the approach was presented using SCW project based on the original mechanical drawing. The design thinking of the SCW was well suited to the deterministic design. The model of this historical design was tested at the time of proposal in 1962 using a 1/4 scale model which moves using an electric motor, and found that it could climb up the staircase. SCW project reviewed the feasibility of the design to climb up/down the stairs without power actuators. The simulation results show that it could be possible to do so.

However, the results also showed that a falling down accident may happen during the stair climbing up/down operation. Since stair steps conditions are different, some ideas of the counter measures were proposed and reviewed. Using the design sketch of a stair climbing wheelchair, its CAD solid model was designed and built to study the design, mechanism and performance of the stair climbing wheelchair in SCW project. The design of this stair-climbing wheelchair is currently used as a teaching material in design classes at MIT to teach how to create innovative design. Even though the technologies have changed from paper drawing to computer-aided design during the past few decades, the heart of creative design approach still remains the same.

The framework of robotics exposure session in CELSP 2013 was derived from the idea of SCW project. Due to the time constraint of CELSP, digital engineering lesson was not included in the session. However, the deterministic design lesson was included in the robotics exposure session and the four MMPT students learned how to apply it to a practice by way of SUMOBOT competition. As a result, the feasibility of CELSP was proved to be effective judging from the student interview assessment. As an initial activity of MMPT, CELSP 2013 made a critical one step forward for the academic collaboration between UT and UTeM. As for the next step, a digital engineering lesson is one of the options to be considered in CELSP because digital information can be shared in real time among geographically separated places, or between UT and UTeM.

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