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# Generation of New Ideas for Product Functions and Engineering Innovation Practices: A Hands-on Project Model for Machatronics Education

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***Abstract***— *The paper describes a hands-on project based approach that utilizing both the creativity and technology skill of students to complete their mechatronics projects. As it has been noticed, the so-called creativity is a fairly unclear term in the engineering domain. The present paper starts with defining the engineering creativity. That is, the engineering creativity is equivalent to creative thinking and innovation. The major outcome of the former is new ideas, while that of the latter is to implement those ideas. In addition to the definition of the engineering creativity, the present paper recommends the so-called "Wen Gu Zhe Xin" model on hands-on mechatronics projects. The name of the model was actually introduced by Confucius some 2500 years ago. From the engineering viewpoint of today, the words include two major steps in developing new products: reviewing and creating. The present report showed these two key steps, together with a brain storming, can be a very effective way to generate new ideas. A hands-on project of the smart paper feeder is used to exemplify the validity of the model. The results are promising. It can be also concluded by using Confucius words again.*

***Key Words***—*Hands-on Projects, Mechatronics, Engineering Creativity, Project-based Programs.*

## INTRODUCTION

It is well-known that the word "mechatronics" was coined from two words- "mechanism" and "electronics," by Mori [1] of Yasakawa Electric Co. in 1969. The original purpose was to promote the new technology to produce new machine tools that integrating traditional machines and electronics. Since then, the domain knowledge has been quickly spread all around the world. In addition, the actual contents of mechatronics have been modified and altered to adapt the needs of different disciplines. The definition of mechatronics may be inconsistent from institutions to institutions. However, the simplest break-down of mechatronics may be at least the domain knowledges of mechanism, electronics and computer software.

Not only the definition of this new discipline is varied in different countries, but the curricula designed to cope with it have been evolved as well [2]-[6]. In general, the courses framework delivered by different departments may be arranged differently. The difficulty exists since to cover "all" technologies in any meaningful manner with appropriate depth is impossible. It is thus easier to design courses in integrated aspects. However, it has been found by most reports that the best teaching mode for this integrated domain knowledge may be through "learning by doing." Or, it is based on the so-called hands-on project approach. Unlike the classical single discipline programs, such kind of approach is really a sharing of theoretical and practical tasks through a team work of students. This approach is believed to be the most effective way of teaching in mechatronics.

Through years of teaching observation on these learning by doing projects, the first author has found that the more significant problem exists when trying to provide mechanical engineering students the integrated training on mechatronics. The problem is not really technological or lab-oriented, but on a philosophy of teaching and learning processes. As it has been noticed, the hands-on project-based learning process is not a traditional and didactically class lecture, but really strongly student centered, which is good for those who are smart and well-organized. Those students are more systematic and well-prepared in most technological skills. Thus, they are more competent to complete their projects even with very little supervision or guidance. However, this is not only educational mission. It is more important to allow those students to progress at their own paces together as a team, no matter they are smart or not. The key resource that a hands-on project normally needs to provide is the learning environment so that the students may complete their project under the atmosphere of competitions as well as co-operations.

In addition to the aforementioned observation, such a project course is actually not only to emphasize the technological skills but other aspects as well. The characteristics of a modern student, to name a few, at least include international view, leadership, willing of team work, communication skills, comprises in disputes, and creativity, etc. Some personal characteristics may be learned naturally through such project based program. Unlike small home works given after hourly lectures, which the students can normally complete their works within one or two weeks, mechatronic projects can only be completed at least in a whole semester. From which, they have to be more cooperative as a team member of the project. Therefore, they are able to learn how to convince other team members, or how and what to comprise in order to reach the final project goal. However, it seems to the authors that the engineering creativity just cannot be learned through those of disputes conflicts or comprises. Moreover, the engineering creativity and innovation can be one of major factors that affect the competitiveness of a modern engineer.

Motivated by this, the present report is to study how and what one can do to incorporate engineering creativity to hands-on projects. Firstly, the definition of engineering creativity and innovation must be clearly defined.

## ENGINEERING CREATIVITY AND INNOVATION

The definition for creativity is somehow unclear and depends on the domain knowledge. In general, creativity is much closer to the 'free-thinking' in engineering. Unfortunately, on the other hand, the 'free-thinking' view of creativity also means to remove the constraints, which normally exist in all engineering problems. Hence, it is clear that smartly solving an engineering problem involves the engineer's creativity. However, problem solving is not engineering. More importantly, creativity has become one of the most essential indices for a modern society. Therefore, to introduce creativity during the learning process of a hands-on project is absolutely essential.

The nature of the so called "creative people" has been given by [7]. In which, they believed that the characteristics of them stems from their personalities [e.g., 8, 9], cognitive ability [e.g., 10], intelligence [e.g., 11], and trainings and experiences [e.g., 12]. These personal factors are all commonly believed to affect the creativity of an engineer. However, creativity is divided into several aspects by recent studies [e.g., 13, 14]. They may be summarized into four categories, including (1) verbal creativity, (2) drawing creativity, (3) creative fluency, and (4) creative behaviours. The correlations among these factors and creativity have been carried out by using ANOVA and MANOVA through more than 400 samples.

On the other hand, the well-known scholar Torrance [15] gives creativity the definition as follows:

> *A process of sensing problems, making guesses, formatting hypotheses, communicating ideas to others and contradicting authority.*

In which their definition obviously is given from the view points of the thinking processes and behaviors of a creative person. This definition is a catchall during the thinking stage. However, it seems to the authors that still something is missing in the definition. In other words, it may not quite close to the engineering domain. To the authors' knowledge, the definition from [16] may be more realistic in the domain of engineering [17]:

- Creativity: synthesis of ideas and concepts by radical reconstructing and re-association of existing ones'; and
- Innovation: the implementation of the results of creativity so that the outcomes have their values.

Thus, from the viewpoint of engineers, creativity may be more or less like the generation of ideas, whereas innovation is putting those generated ideas into actions by implementing at least one of them into products. In addition, the outcome products must have more value than existing ones. Those definitions that are potentially valid have been thoroughly reviewed by [18]. Similar definition that used for accessing the participant creativities of robot contests is also given by [19], and shown in Fig. 1.

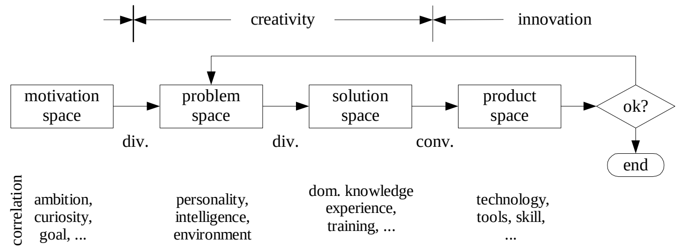


FIGURE 1
ENGINEERING CREATIVITY AND INNOVATION ON A PROJECT.

Review all those differnt definitions that are considered appropriate for engineering field, especially for hands-on project, several keywords have been noticed. They are thinking process, sythesis of ideas, problem solving, implementation, product, higher values, etc. Actually, [20] suggests to access the engineering creativity only by its novelty as well as the added value. This may let the authors come to summarize the term "engineering creativity" used in the present paper is in fact to include: (1) creative thinking process so that novel ideas can be generated, (2) further innovatively implementing them into real products, and (3) those outcomes must preserve more value than ever. Thus, considering a hands-on project, the engineering creativity injected to students may include the following aspects: styling, functional, implementing and material applying ones.

In fact, a nationwide robot contest [19], similar to hands-on project programs, which is sponsored by TDK, have been held every year since 1997. The contest provides a chance for the engineering students to show what they can achieve through the carefully designed robots. However, [19] studied the compiled reports from '97 to 2000 for near 150 teams, by comparing the behaviors and performances of participants before and after the contests. Through analyzing and grading the technique attributes of robots, the study found that the results are quite promising in the sense of attracting students to take part in the contests. In other words, an event like the robot contests can certainly enhance and integrate the ability of mechartonics. The creativity can be observed from the individual participating team members. However, the yearly increase of engineering creativity can be hardly found.

## NEW IDEAS FOR MECHATRONICS PROJECTS

All product development can be deployed in terms of a few stages. They may include like planning, conceptual design, design embodiment or detail design, verification and refinement, and production ramp-up, etc. Certainly a hands-on project that mimics a real production system would not be different. Unlike the product development of companies, in which the products may have been limited in a certain area, projects designed for mechatronics education generally have more freedom to incorporate topics of all areas. For that reason, the authors recommend the topic or subject of projects has to be assigned by the project instructor or supervisor. Student-formatted or student-generated topics are not recommended. However, the assigned topic shall not be too specific, although clear instruction is necessary. Or, it has to be heuristic enough so students know how to start the first step of their projects. Do not assign the project by giving step-by-step work sheets. In other words, the assignment is just similar to let the students have feeling of being in that topic-related industry, so they may be able to imagine the environment they are facing with. Therefore, they can start planning their project, which is the first stage of a product development.

Once the direction of a project is given, the students are asked to assure what they really want to do with the subject. This also means that they have to identify or narrow down the subject to the size that they are able to handle or to complete within the given period. At this stage, it first lets students to diverge their thinking, then to converge to a more specific direction. By doing this way, it is possible to clarify the problem definitions. Meanwhile, the goal and the corresponding engineering specifications can be thus set by the students themselves, instead of the instructor. Refer to Fig. 2 for the block diagram that illustrates the recommended steps.

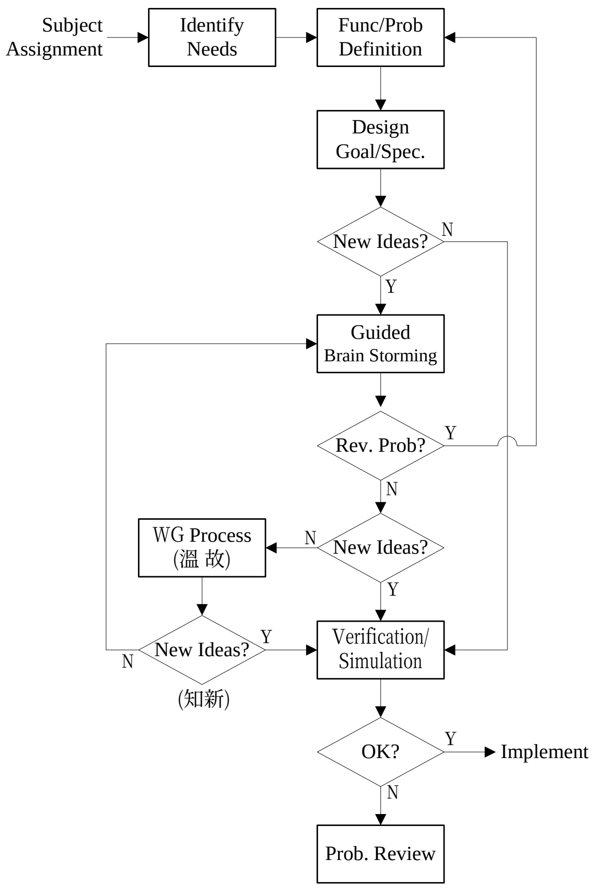


FIGURE 2
CREATIVE IDEA GENERATION WITH WEN-GU-ZHE-XIN PROCESS.

The generation of new ideas involves in Fig. 2 is called "Wen-Gu-Zhe-Xin" process, which is in Chinese pronunciation. The real meaning of this term is similar to "review old, then to know novelty." In other words, it actually says two different stages: review the existing technologies, and create the new ones. From the authors' viewpoint, however, the former may be even more realistic. Or, "Wen-Gu" says that if one encounters a problem, then goes back to the basic. And see whether there exists a possibility to overcome the problem from the fundamental view or not.

Back to the basic! That is, to decompose the problem into several smaller pieces. Try to re-arrange and re-combine those pieces in a different ways and to see if there are possible new ways exist. As a consequence, inspired ideas may just pop up. The next step is to verify the feasibility of the new ideas. Refer to Fig. 3 for schematic delineation [21].

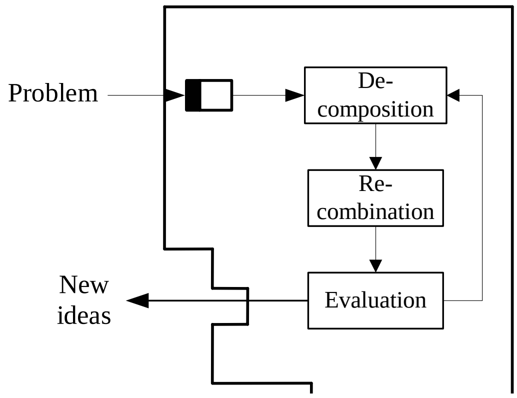


FIGURE 3
TURN PROBLEM INTO NEW IDEAS.

In order to demonstrate the abovementioned process, an example project given in the senior at NTUT is presented below. This hands-on project is designed for a team of three members for a year or two semesters. However, since it was only two students selected, it was completed only by the two.

## AN EXAMPLE: A SMART PAPER FEEDER

The project is given by the following descriptions:

> *A printer for computers has been widely used in the university. You are not satisfied, are you? Your mission is to 'improve' functions of printers. That is, your team has to generate new ideas and then verify the feasibility of them. In the meantime, mechatronics you have learned from class has to be implemented on your project.*

By reading the assignment description, it clearly points out the direction of the project. Namely, the subject has been confined in the printer related ones. However, the specific topic is still open and waiting for further clarification. This will enable the students to bridge the open gap. In the meantime, they can define the problem themselves, instead of just passively waiting for the guidance.

Once the team obtained the above assignment, they stared a random oral survey to clarify what they were going to do with the project. The survey was simple. They just went to the library and arbitrarily asked students what and how they wanted their printers do if it is possible, in addition to those functions already built in. It turned out quite surprised outcomes. For example, the collected functions include:

- style: light, portable, as cute as possible, etc.
- can easily integrates with NB
- able to print CD directly
- able to print on papers as well as thick cardboards

- USB only, no additional power cord is required
- inks can be re-used or recycled
- ‘embossed’ printing

and so on. Among them, several can be combined into one. Finally, the team decided to complete their project focused at adding a new function to printers. More specifically, the team is to designed a new paper feeding unit so that printers are able to print objects with thickness up to 10 mm, in addition the normal papers.

A few ideas are sketched first before put into 3D models. Figure 4 shows the final 3D model and it outlook. In addition, Fig.5 shows a creative idea to integrate a portable printer with a laptop computer. Nevertheless, the problem definition of the present example has been set. The next step is to complete the project by adopting all known technologies. However, before starting that, one has to review all the existing paper feeders and to assure the added function is novel. This review process is called “Wen-Gu” (in Chinese) process.

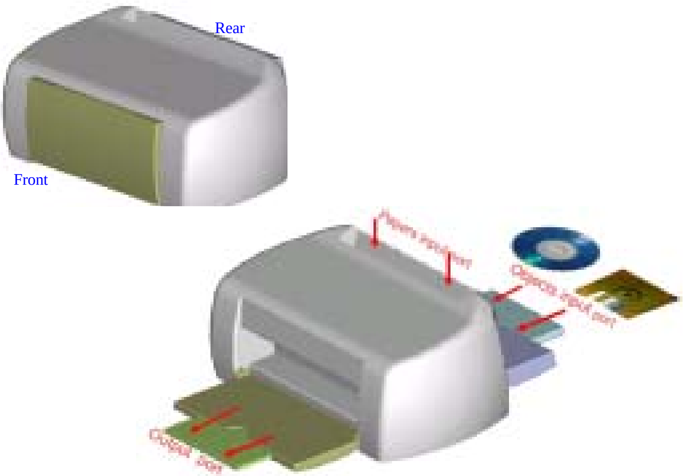


FIGURE 4
SMART FEEDING UNIT FOR A PRINTER TO PRINT THICK OBJECTS.

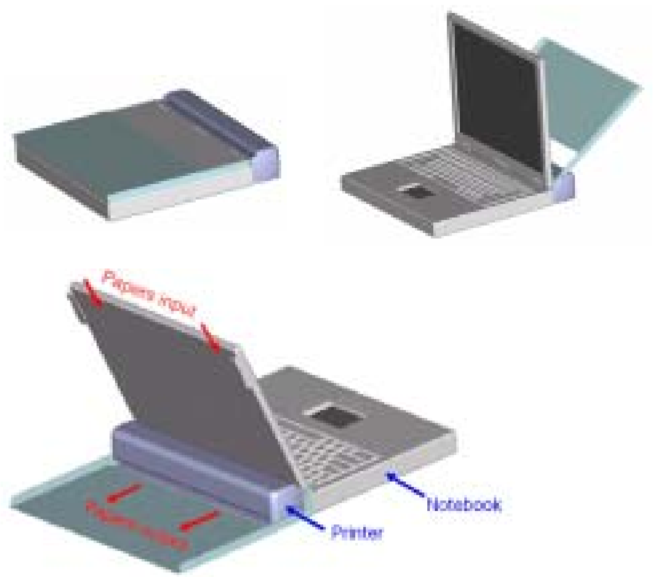


FIGURE 5
AN IDEA OF AN NB INTEGRATED PRINTER.

## WEN-GU: CURRENT STATUS

In order to exemplify the so-called “Wen-Gu” process, the current status for the paper feeding units in current printers will be reviewed in this section. However, since there are too many types and brands to completely review, one just chooses a few that commonly seen in the market. For others, the small deviation may be observed.

### Dot Matrices

The early printers are the so-called ‘dot matrix’ type. They are good for imprinting a few carbon copies simultaneously. Figure 6 shows the paper feeding mechanism of such a printer that commonly seen in the market. Basically, the mechanism composes two geared belts, one along each side, to feed papers. Thus, their counterpart, papers, has to be punched holes with the same pitch as that on the feeding belts. In addition, the two gears on each belt have to be well aligned so that the forward/backward motions of the two belts can be kept in the same. Meanwhile, the positioning accuracy completely depends on the accuracies of the pitch and hole sizes on the paper. Therefore, this feeding mechanism has poor positioning accuracy and is out of date.

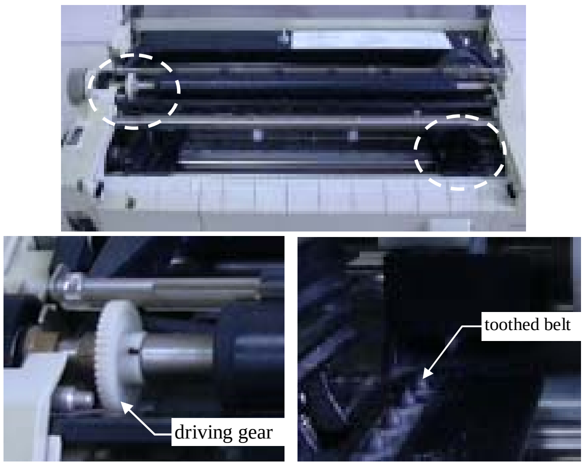


FIGURE 6
THE FEEDING UNIT OF A DOT MATRIX PRINTER.

### Ink Jet and Laser Jet

The shortcoming of the dot-matrix type printer is quite apparent. The most market of this type was thus soon replaced by so-called ink jet printers. Unlike the dot-matrix ones, the feeding unit does not provide any gear teeth. Instead, two rollers are installed for responsible of feeding papers. Figure 7 shows the unit. In general, one of the two rollers is used for guiding only. It normally divided into several shorter sections and all made of soft materials. And, the other is for driving and driven by a motor. The basic feeding mechanism of this feeding system stems from the friction force that exists from pressing the driving roller to the guide. Normally, the pressing roller has an adjusting spring for manually tuning the pressing forces and the gap between the two rollers.

The position accuracy of this type is believed to be much better than that of a dot matrix. However, there exist also shortcomings. For example, the skewness of one or two rollers can easily result in difficulty to parallel the papers. Besides, the surface condition, especially from the driving roller which is normally made of rubber, may wear out after a certain period. Furthermore, it can easily jam the fed paper if it is too thick. However, it costs less and is easy to manufacture. To the authors' knowledge, printers of this type are still popular in today's market.

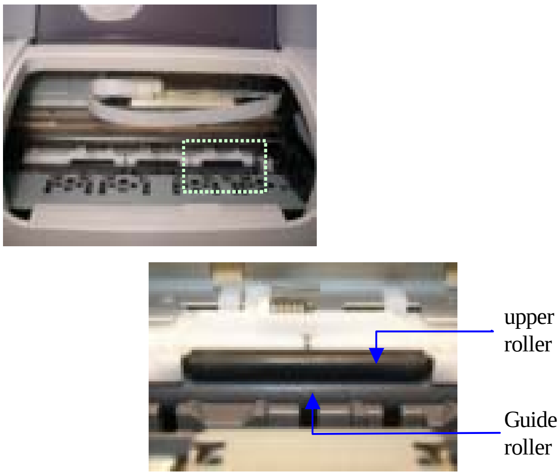


FIGURE 7
A TYPICAL FEEDING UNIT OF INK-JET PRINTERS.

*De facto*, the feeding unit of this friction roller type has been modified and improved in many ways. For instance, Figure 8 shows an Epson's model Photo 2100 [22] which is claimed to have the capability of printing on a CD. A tray that fits the size of a CD has been added. This model is quite fancy but the cost is high as well. To the authors' knowledge, this type of paper feeder does not have good responses from the consumers.

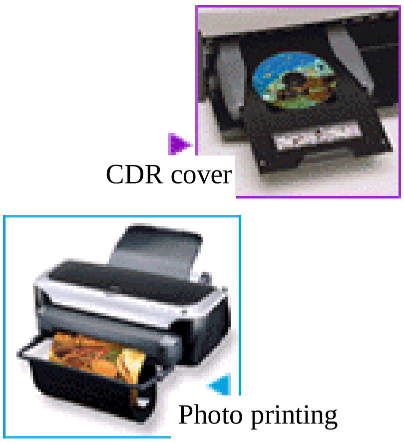


FIGURE 8
A PAPER FEEDER WITH A CD TRAY.

Since this type of feeding system is cheap and relatively reliable, it has been used for laser jet printers. Figure 9 shows a typical feeding unit from HP's laser jet printers [23]. It can be clearly seen that there exist two rollers, which are the key technology of the feeder from the picture.

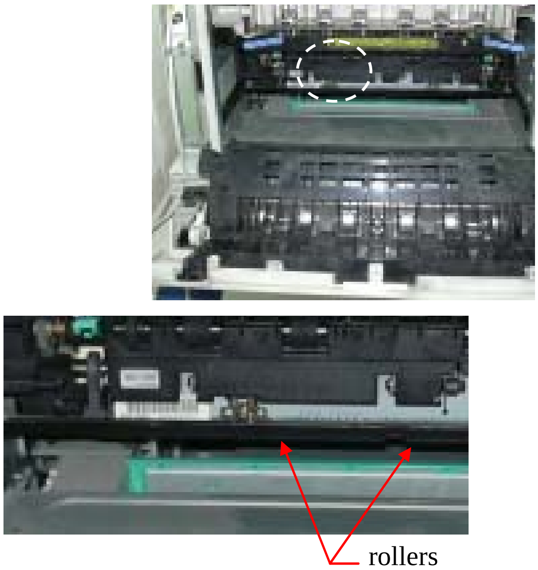


FIGURE 9
FRICTION ROLLERS OF AN HP LASER JET PRINTER.

**Thermal Transfer**

Unlike the former printers, a thermal heat transfer printer requires to move the printing paper back and forth several times in order to overlay the image with different colors. Thus, the feeding mechanism normally includes a capstan driving roller, which is driven by a motor, together with an upper rubber roller. The capstan roller is made of light metallic material (e.g. aluminum alloy) embossed with equally spaced small dots (or similar geometry) that similar to Braille. Once the capstan is uniformly pressed by the rubber roller, the interface between them generates much higher friction than that of the traditional friction rollers. The rubber roller may even have dents that developed by the embossed dots on its surface. The dots on the capstan surface play an important role of moving the paper back to the origin each time when one color being completed. Therefore, the higher quality of an image is required, the more precise of such motion has to fulfill. And, the surface characteristics of the capstan roller can completely determine the moving and feeding precision. Figure 10 shows a typical capstan and the rubber roller. Notice the surface characteristics of the two rollers.

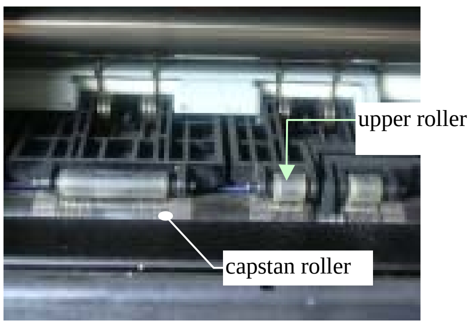


FIGURE 10
A FEEDING UNIT FOR A THERMAL TRANSFER PRINTER.

## ZHE-XIN: THE PRESENT DESIGN

After thoroughly investigate the currently using feeding units, all the team members have got quite well knowlege of the whole mechanisms, sensors, and controllers. In the meantime, the goal of the project can be then set. Since the time limitation, it has been set to verify the ideas shall be workable. In addition, it has been noticed that there are two major factors that affecting the performance to the paper feeding. They are (1) the friction force between the paper and feeder interfaces; and (2) the gap of the interface, which in turn also inter-correlated with the friction force.

After several dicussions, the team has decided to ignore the feeding speed and inks for now. These two factors are also important. However, to avoid putting too much effort on the subjects that outside the team members' domain knowledge, the team has determined to complete their ideas first. The discussions also clarify what and how good they intend to reach.

The following sections will introduce their ideas to attain their design goal and complete this example project [26].

### Mechanism

From the theoretical point of view, the currently used paper feeding is based on the friction force that is generated from the normal contact force exerted from the two contact bodies. To increase the friction force, two factors must be controlled: the coefficient of friction and the normal forces. And, it seems to the authors that pushing paper is simplest and cheapest way. And hence, the present design keeps this friction type after many re-examinations of current designs.

On the other hand, in order to generate a large and controllable normal force, new design ideas have to be generated prior to embodiment design. In order to reach this target, the basic functions have been first analyzed in addition to study the current status. The creative methods introduced in [19, 21] have been applied at this stage and several new ideas were generated through those methods. It has been found the brain storming method is the most effective one. For example, Fig. 11 shows two typical ideas that have been discussed during the idea generation period. However, they were all discarded since poor precision may occur during the assembling or difficult to manufacturing.

Figure 12 shows the one that has been selected for the mechanism prototype of the present feeding unit. That is, it combines the two ideas in Figure 11 in addition to several small modifications. It can be clearly seen that the new design still encloses the central idea of the friction rollers. Besides, anticipating the roller is driven by a stepping motor, a lead screw has been added. In the meantime, it can also see that there are two guide bearings or surfaces, which are mainly for uniformly increasing the force distribution. In fact, the roller has been designed to cover a fine sand paper of #500 in addition to soft rubber. Hence, a higher friction coefficient can be expected. Figure 13 shows the picture of the two rollers, where the sand paper has been covered on their surfaces.

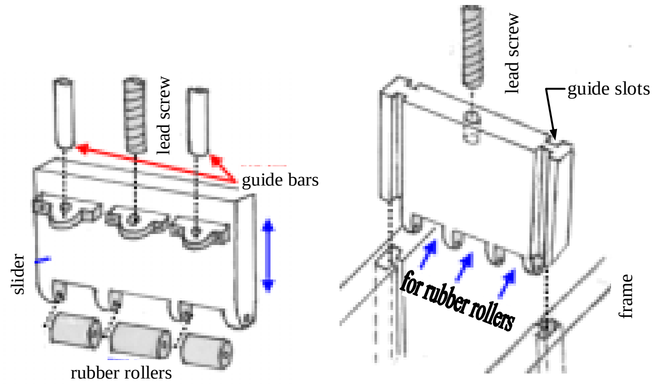


FIGURE 11
TWO TYPICAL IDEAS FOR A NEW FEEDING UNIT [24].

### Sensing Devices

There are two types of sensing devices have been installed. One is to sense the pushing load from the rubber roller on to the driving roller. This downward loading signal is definitely proportional to the amplitude of the friction force between the two rollers. However, since it is difficult to directly measure the contact force, instead, one has to measure the bending moment exerted from the support of the driving roller. The basic idea is depicted in Fig. 14. In this case, a strain gauge has been applied since it costs less and is quite reliable.

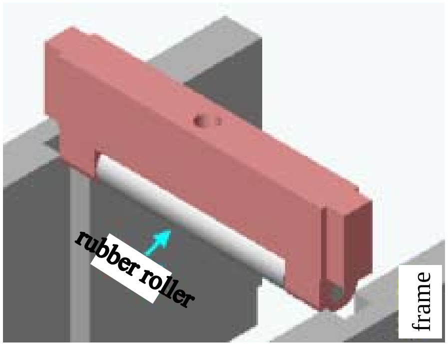


FIGURE 12
THE SCHEMATIC 3D MODEL OF THE PRESENT DESIGN.

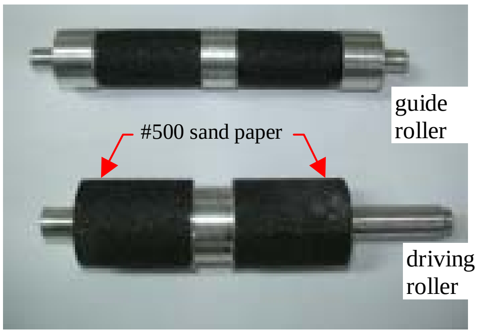


FIGURE 13
THE TWO ROLLERS OF THE PRESENT DESIGN.

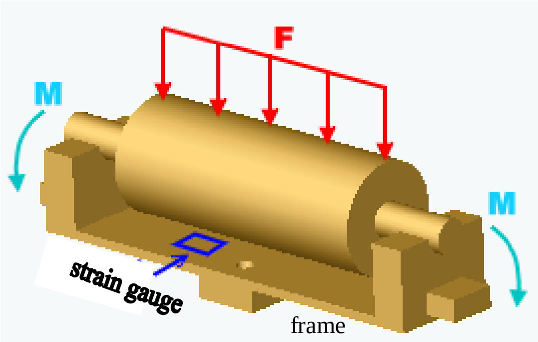


FIGURE 14
THE DEVICE FOR SENSING FRICTION FORCE.

The second type of sensors is the micro-switches (MS), which are used for detecting the position of the printing paper. There are three MS have been included in the present feeder. They are used for (1) paper arrival (MS1), (2) paper in place (MS2), and (3) end of paper (MS3), respectively.

### Control and Monitoring Flow

The control flow of the present feeding unit is quite simple, and briefly described in Figure 15. And, an ATMEL 89C51 (8051) [25] has been chosen as the micro-processor in the current stage. The necessary program is established from Window Notepad before compiling into machine code, and will not be shown in the present report. Readers are referred to [24].

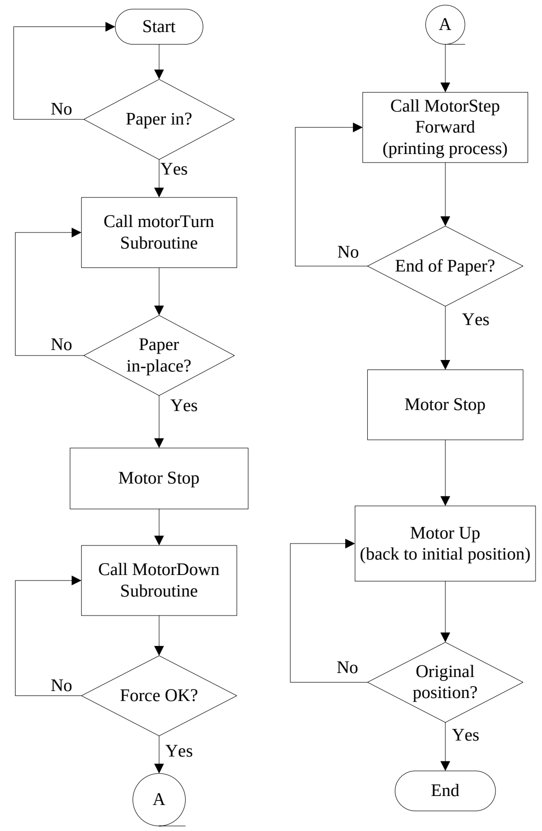


FIGURE 15
CONTROL FLOW DIAGRAM.

## EVALUATION: OUTCOMES AND RESULTS

### Mechanical Parts

In order to verify the idea depicted in the last section, all mechanical parts are designed by using a 3D commercial package (Solidworks) before they are made. For example, Fig. 16(a) shows the downward mechanism together with the stepping motor (4$\phi$ × 12V), in CAD model while Fig. 16(b) is its completed product assembly. One is able to see their similarity. Nevertheless, the CAD tool has been widely utilized during the generation of the present feeding unit. Since the main purpose of the present study is to verify the feasibility of the novel idea, only the scale-down size of the feeding unit was made. All mechanical components are machined in the lab of NTUT, in addition to some small standard elements (e.g., plastic pinions) can be easily bought in the market.

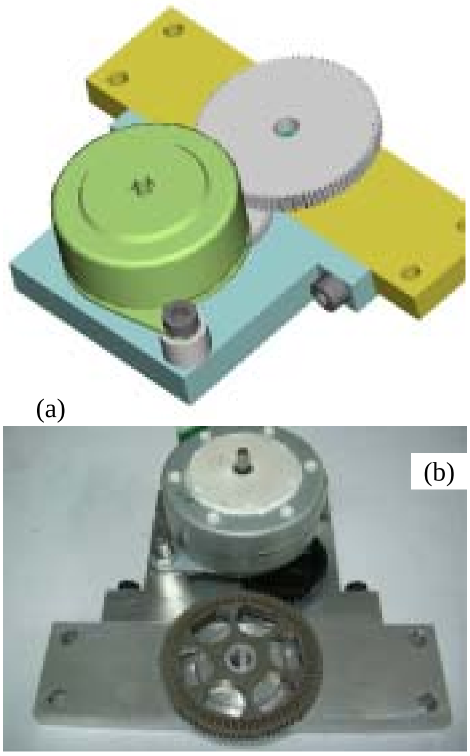


FIGURE 16
THE DOWNWARD MECHANISM ASSEMBLY.

Since the driving stepping motor normally doesn't provide enough torques, to increase its output torque equally means more mechanical elements have to be added. In this situation, the biggest problem in manufacturing these parts is the fit of two parts and the tolerances of the parts. However, after several trials, quite satisfactory components can be produced in the lab. The components and sub-assemblies are broken down as shown in Fig. 17. In addition, the complete assembly is shown in Figure 18. In the latter figure, it has shown three main sub-assemblies in the figure: the feeding unit, the power supply, and the control unit. Even though the final product has neither been integrated into as one complete set nor pretty enough, it works as the specified design goal.

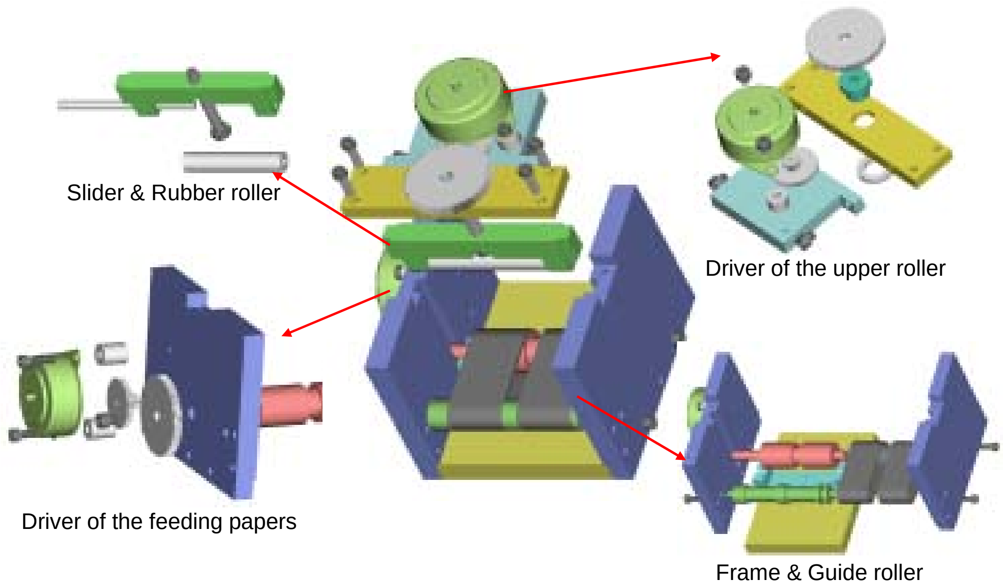


FIGURE 17
COMPONENTS AND SUB-ASSEMBLIES OF THE PRESENT PAPER FEEDER.

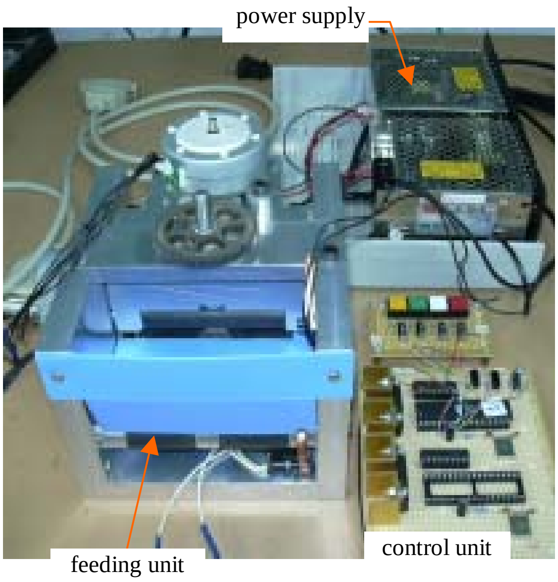


FIGURE 18
THE THREE SUB-UNITS OF THE FEEDING UNIT.

### Function Tests

The prototype feeding unit, including the control, is experi-mentally tested after it has been assembled. In order to see whether the original idea and design goals are matched or not, several different objects are purposely inserted into the completed unit in addition to thin printing papers. These extra thick objects are supposed to be very possibly being printed by a user. Figure 19 shows a 3.5” floppy disk is tested when the cover is open so one is able to see the internal mechanisms.

For every object, thirty (30) times are tested, and pass or fail fully depends on if the printed object could smoothly go through the unit. In case the object is jammed or zigzagged during it goes through the unit, that verification is then graded fail. The experiment results are tabulated in Table 1. Since the tests of general papers are used as the ‘go-and-nogo’ screen, the results are not shown in the table.


FIGURE 19
A 3.5” FLOPPY DISK IS FED INTO THE NEW FEEDING UNIT.

### Post-Test

From the summary of the thick object printing tests in Table 1, one may see the present feeding unit may not be able to obtain reliable results for cases of CDR and corrugated card papers. The main reason for the former one is that the limitation of its geometric shape is circular. Thus, it is difficult to keep inserting a CDR properly aligned with MS2. As the consequence, the CDR may jerkily sway to one side, instead of smoothly moving. Even though it did go through the entire span up to MS during the tests, the results have been graded to fail. However, fail results in CDR feed-in may stimulate the team to generate some other ideas. Actually, when the feeder been designed at the beginning, it even does not come into mind with the geometric shapes other than rectangular ones.

| Objects | Trials/Fail | Pass rate | Remarks |
|---|---|---|---|
| 3.5" floppy disk | 30/0 | 100 % | |
| 700 MB CD-R | 30/2 | 93.3 % | |
| Acrylic, 3 mm | 30/0 | 100 % | |
| cardboard paper 6 mm corrugated | 30/3 | 90 % | |
| cardboard paper 10 mm thick | 30/0 | 100 % | |

TABLE 1
TEST RESULTS FOR VARIOUS PRINTING OBJECTS

For the reason of fail in tests of corrugated cardboard, on the other hand, the main reason stems in the non-homogeneous of the board. Those of reinforced areas, it appeared stiffer than those of none. After repeated tests for 30 times, the cardboard has been pressed and deformed to completely different from its original shapes. Should real printing happen, this failure can be completely avoided, since repeated 30 times printing on a same object would be unrealistic. However, since the embedded controller still works fairly well as what the design goal sets up.

## CONCLUSIONS

It is noticed that to fuse the engineering creativity to mechatronics projects is as important as technologically completing a project. In order to inject the engineering creativity to the hands-on project program of mechatronics, the so-called "Wen Gu Zhe Xin" (溫故而知新) model is recommended in the present paper. These four Chinese characters were actually introduced by Confucius some 2500 years ago. From the engineering view point of today, the words indicate two major steps in developing products: reviewing and creating. The present report showed these two key steps, together with a brain storming, can be a very effective way to generate new ideas. In addition to the model, an example project is also presented to substantiate the validity of the model. The results of the evaluation are promising. It just likes old Confucius said, after the aforementioned four characters, "Ko Yi Wei Shih Yi" (可以為師矣). In other words, the whole sentence- "If one starts reviewing existing technologies and is able to generate new ideas, then he is a master in that area."

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