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Trial of IT Education Centering on Motion-Control Technique of Robot Hands

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Abstract

As part of the undergraduate curricular reform at our university, we have begun offering on a trial basis a workshop course in which we introduce the concept of barrier-free engineering. There, the students partake in a group design project with the aim of creating a robot hand that can 'communicate' by movement; the long-term goal from the faculty research standpoint is to realize a robot hand capable of sign language. This attempt is discussed in terms of the issues of engineering education, certain technical issues pertaining to the introduction of a new 'robotic' concept, and in terms of its societal implications particularly as a component of IT.

1. Introduction

Japanese engineering schools are today seeing a gradual decline in the number of applicants. Yet they must step up to the challenge of reforming their curricula in order to cope with today's industrial environment, which is becoming increasingly IT- and control-oriented. Moreover, such curricular reforms must be carried out with the full cooperation of the current teaching staff.

This paper reports on the attempt undertaken at the Polytechnic University for a departmental-level reform which is in line with the University's higher administrative policy to establish an IT Center. While the Polytechnic University is rather unique in its purpose and program among Japanese universities, we believe that a presentation of our proposed project on motion-control technology centered on robot hands can make a contribution to the engineering education community at large by providing an example of a hands-on, workshop-based instruction.

After touching upon the University's role within Japan and in the larger context of engineering education world, we describe the recent curricular reforms which aim at establishing a barrier-free technology for the IT era. As a concrete target, we have initiated a project to create a 'sign-language robot'. We discuss the associated technical issues referring to a trial undergraduate course. Finally we discuss the social/educational implications of such technology.

2. The Polytechnic University

The Polytechnic University is the only institution in Japan set up to educate vocational instructors and conduct research on human resources training. It reports to the Employment and Human-Resources Development Organization (EHDO), and is linked to 17 colleges and 60 skill formation centers to form a nationwide network of human resources development. These facilities are funded by interests generated from labor insurance moneys collected from Japanese workers and employers. Table 1 shows the relevant organizations associated with the University (see Reference [1] for details).

Table 1. Outline of EHDO (relevant to engineering training)

Facilities	Numbers
Polytechnic colleges	17
One type provides two-year courses for high-school graduates, and the other type offers applied courses for those who have completed a two-year course.	
Advanced Polytechnic Center	1
This Center offers human resources development seminars related to advanced knowledge and technologies that are not available at local skill formation centers. It also provides a leading role in disseminating information and knowledge to other Polytechnic Centers.	
Skill Formation Centers	60
These were established at 60 locations all over Japan and provide various vocational training services through a range of programs such as human resources development seminars for employees and skills development for job seekers. They also play a role as local centers for continuing engineering education by offering facilities/equipment and providing business owners with support on conducting training for their organizations.	
Lifelong Human Resources Developing Center	1
This Center, known as the ability garden, provides two services. It conducts surveys and research to develop and enhance the vocational capabilities of white-collar workers, and it offers leading and practical training, information, support and consulting on the basis of the results obtained.	

The undergraduate program, which constitutes the core of the University, comprises the following departments:

- Mechanical Engineering
- Electrical/Electronic Engineering
- Information and Computer Science
- Architecture/Design
- Rehabilitation Engineering and Mechatronics

There is also a graduate program as well as several other courses, among which the following are relevant to this report:

- *Refresher courses*: These are offered to working instructors who wish to keep up with recent developments in their fields of specialty, or learn new technical subjects; upon successful completion, they will receive certification.
- *Robot Technology Course for foreign instructors*: This is one of several programs offered, under sponsorship of the Japan International Cooperation Agency, to non-Japanese vocational instructors from developing countries.

The educational reform being undertaken has two underlying components: the overhaul of the undergraduate program, and the university policy to establish an IT Center, the purpose of which is to conduct IT research and provide instructional material to EHDO facilities. This has affected the Department of Electrical and Electronic Engineering Department, resulting in the creation of two divisions.

Traditionally, instruction and research in the Electrical Division have leaned heavily toward subjects in power engineering, and so we had been seeking in recent years to incorporate more subjects in the field of control technology. A few years ago, we began offering an intensive 6-month Robot Technology Course for overseas technical instructors; at the same time, we began experimenting with a course aimed at control engineering majors, based upon our experience with this Robot Technology course.

Restructuring at the Department consisted of installing two areas of specialization: power engineering and control systems. The latter, which covers the subjects of electronic circuits, motion-control software, simulation, sensors, and measurement, was further strengthened by the recent addition of a specialist in robots for automated assembly lines.

3. Barrier-free information technology - Our new educational framework -

We note that ‘barrier free’ or ‘universal’ design is a concept that has become quite relevant to today’s information technology. Aimed at students in the Control Course of Electrical Engineering Division, the two principal authors, Terauchi and Kenjo, began teaching a lab course on control systems based on multimedia educational technology, where they hoped to encourage students to explore beyond previous practices in conventional robotics and factory automation. The former has conducted linguistic research on sign language and participated in developing an animation system based on electronic coding of sign language [2]. The latter has developed microprocessor-based educational devices and lab equipment, which have been extensively used at EHDO technical training facilities as well as many technical colleges and universities. He has also experimented in Internet based remote education, jointly developing ‘distance labs’ for teaching advanced motor control [3][4], and has developed instructional software for mechatronics [5].

Below we describe the workshop course for creating prototype message-sending robot hands, and discuss relevant engineering education issues. We then discuss a research project to design a sign-language robot, as part of the authors’ research and training activities based on our new educational framework.

4. Trial workshop course

The Polytechnic University is rather unique among Japanese universities in that students spend a considerable amount of time in workshop training. Workshops and labs are a necessary component of technical education, supplementing classroom instruction and providing a greater motivation to students by giving them hands-on experience; it has the additional benefit of drawing out their creativity and stimulating innovative ideas. In particular, a working knowledge of many issues in control theory, such as efficiency, cannot be imparted to students by classroom lectures alone.

As our first trial, the workshop course in control engineering practices (i.e., the design lab for robot hands described above) was offered once a week for 17 weeks. Fifteen juniors specializing in control systems and a working instructor enrolled in the class. The course started in April 2001 and consists of three segments (the following curriculum is tentative):

- Simulation of DC motor speed/position control
- Controlling a stepping motor using a microprocessor
- Prototyping a message-sending hand robot

The first segment is aimed at providing the students with the basics of permanent-magnet DC motors (a common motor they have probably seen and used in toys as youngsters), and offering them practice in modeling technique using Visual Basic. A few students displayed keen interests in Visual Basic programming for dealing with the differential equations describing the motor (based on a version we developed [6]). However, most students had trouble with numerical computations of differential equations and the concept of feedback control.

On the other hand, they showed a strong interest in driving stepping motors in the second segment, using a Z80-based micro-controller and machine-language programming.

After these two segments covering basic motion-control subjects, the students were given the assignment to create a sign-communication robot hand with three fingers.

The students were then encouraged to be free from conventional design concepts as practiced in precision machines. To tackle the assignment, the 16 students were grouped into four teams. While not all teams seem to be functioning well, one is a relatively successful case. In this team, the working technical instructor (who is taking the class as a refresher course) has assumed a natural leadership, while the remaining three have put their different talents to work. This group has set its goals on constructing a robot hand that can form the three hand configurations used by baseball pitchers to throw the straight, curve, and forkballs.

Toward the end of the course, we plan to cover the circuit arrangements for the motors used in the robot hands. Finally, a week will be spent in December to give the students some practice with single-chip processors, which will be used to drive their final projects.

This course will be offered again next year incorporating possible improvements based on this year's trial.

5. Issues of educational technology

Through this first trial, which is still in progress, we have become aware of several issues. Firstly, this sort of practice requires that the team, as a problem-solving unit, is able to draw upon many disciplines, including mechanics, dynamics, electric machinery, electronic circuits, microprocessor interfaces and software, as well as practical shop skills in handling various tools. It is quite unrealistic to expect students (in Japan and perhaps in other countries as well) to acquire all of these subjects by their third year (when the course is being offered). There are some students at this level who have not even acquired such basics as analog/digital circuit design and practice, or worked with materials like plastics, metal, and wood.

To begin with, each team must decide upon a suitable actuator at a very early stage of the project. A DC motor, stepping motor or solenoid would normally be considered as viable options for this type of project, but students at this level have not received sufficient instruction on these subject matters as yet. The first two segments were intended to give them basic knowledge of the two types of motors, and it was not unsuccessful in this respect. However, they became more involved with the process of designing using Visual Basic in the first segment and machine-language coding in the second rather than making a technical comparison of these different actuators.

A basic issue pertaining to actuator selection surfaced when we realized that using only conventional electromagnetic motors including ultrasonic motors might be inherently realistic for sign-language hand machines. We thus started to explore the possibilities of shape-memory alloys. The students' reactions to the new actuator varied: a few students could not even begin to consider making a comparison between these materials and conventional motors, while others were soon busy taking measurements of force against current. Upon noticing that the alloys displayed 'natural', flowing movements, some students became enthusiastic about their prospective application in sign-language robot hands.

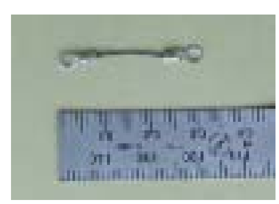
Another important issue is that the lab must have ready at hand a store of materials and parts, from which students can choose so that they could get started on their respective projects immediately. The use of parts from various commercial kits are often helpful, but not always satisfactory since they fail to draw out the students' creative initiative. We then need to determine what kind of prefabricated components are best suited from the standpoint of engineering education.

A further important issue is the determination of motion converter. Fig.1 shows some actuators and motion converters we prepared for the course.

(a) Tamiya's planetary gears with a DC motor and similar devices

(b) Semi-professional stepping motors and circuit kits

(c) Professional DC motors and the stepping motor



(d)Various solenoids, (e) Shape-memory alloy

Figure 1. Various sorts of existing actuators

The toy gear-heads shown are reasonably priced and easy to use when creating various step-down ratios, but are lacking in power and accuracy. The professional ones are rather expensive and not so easily combined with various motors and loads. There are no models available with specifications (and price) that fall in between these two extremes.

6. AGAPE sign robot as a research project

We now discuss the project from the research standpoint. In the not-so-distant future, we are told, robots will expand from automated production plants to homes and hospitals, where many 'helper' robots will assist people in carrying out their daily tasks. Some of these robots will very likely specialize in communicating in sign language. A robot that can translate between verbal and sign language will clearly contribute to barrier-free communication; this is our long-range target.

We use our hands for many purposes: to hold and carry objects, play the piano, convey messages, etc. Sign language is a visual language that employs hand configurations, upper-limb movements, as well as facial expressions and gestures. Hand signs entail moving the fingers of either hand or both hands. It is also possible to use "finger spelling" to express words (and sentences) using the so-called manual alphabet, which are defined by combinations of hand configurations. In Japanese Sign Language (JSL), finger spelling is often used to express proper nouns or new words (see Fig.2).

Mouthing :
"PASOCON"
Right hand :
Finger spelling "Pa"
Left hand :
Sign {KEY-BOARD}

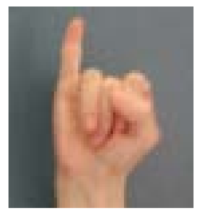
Figure 2. First author using both hands to sign the word "personal computer"

The utility of designing a robot hand that can express the manual alphabet comes from the fact that many hand signs in sign language are similar to the letters in manual alphabet. The letters of the manual alphabet can be combined with various upper-limb movements in the process of building up sign language vocabulary.

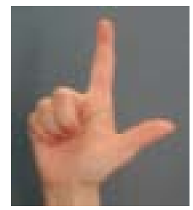
Face-to-face learning is effective for understanding (corresponding to hearing), but for creating signs (corresponding to speaking), the learner must switch the movements of right and left hands, but this is not easy for the beginner.

3D animation on the display is not always satisfactory because it lacks depth information. If a sign-language robot is available, it can prove to be a useful learning aid for those studying sign language since a particular movement or expression can be repeated, at the actual speed or at a slowed-down rate.

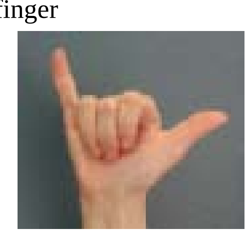
As our initial research goal, we hope to create a sign-language robot that can sign "I love you" in ASL (American Sign Language); we call it the AGAPE I robot. (*AGAPE*: a love of God for man.) This version of "I love you" has become an internationally accepted expression (see Fig.3). Through this project, we will investigate such fundamental issues as actuator selection, control strategies, and the additional effect of depth information when combined with 3D animation.



'I' by raising the little finger



'L(ove)' by raising the thumb and pointer



'Y(ou)' by raising the thumb and little finger

'I love you' by raising the three fingers

Figure 3. Signing "I love you," an internationally accepted expression

7. Survey of robot hands and our goal

There has been considerable progress in the design of robot legs and feet in Japan recently, resulting in such practical biped robots as the HONDA P3. On the other hand, the design of hands, or manipulators, which forms a major area in robot engineering, still faces many technical challenges. It is said that a certain company had already designed some 2000 types of factory automation robot hands by 1980[7]. A five-finger robot hand was prototyped in the 1970s as an artificial limb, but the fundamental design of such artificial hands has remained largely unchanged to this day, except some highly sophisticated hands such as those used in space applications.

It would be a very difficult task to design a robot hand that can mimic the human hand in all its functions. Here we review previous research in robot hands and discuss what design requirements might be needed for a sign-language robot.

a) Most robot designs are based on a precision-control mechanism. Accurate speed- or position-control, required in FA design, may not be important for the sign-language robot since there is no need to grasp or hold objects.

b) Three fingers are normally sufficient for the purpose of holding an object. In an artificial hand, the ring and little fingers often obstruct the other three fingers' motion. A hand developed by the German Aerospace Research Center has four fingers. NASA's Robonaut has five fingers, but the ring and little fingers are manipulated as a single unit[8].

c) Conventional motors generate audible noise, tend to be heavy, and are usually made of metal components. Quiet operation would be preferred for a sign-language robot.

d) A sign-language robot would require a high degree-of-freedom. (The human hand has about 30 degrees-of-freedom, while a robot hand at the research level typically has less than 10.) The HONDA P3 has five fingers but it is unable to abduct (i.e., open out) the fingers (and make a V sign, for example, by abducting the pointer and middle fingers). NASA's Robonaut can abduct the first and second fingers, but the third and fourth fingers have limited movement. The most promising robot hand, designed by Sugiuchi, has 17 degrees-of-freedom [9]. An important ability is for the palm to be able to fold when, say, grasping a bar; this is useful when creating several letters in the manual alphabet.

e) Most of the grasping robot hands so far designed seem aesthetically unappealing to many people. The visual image is highly important in sign-language hand movements.

Our next goal after the **AGAPE** I will be to investigate the hand-spelling capability of Sugiuchi's robot. Eventually, we intend to investigate new design approaches to achieve a degree of communication practicality. Indeed, the thrust to develop a sign-language robot hand can provide new horizons in the field of small precision-motor technology, which many workers feel has fallen into a stagnant state, with the bulk of research efforts being channeled into refining and extending existing technologies.

8. A fundamental mechatronics issue

From the very outset, students enrolled in the workshop course are faced with the issue of actuator selection. There are several technical reports on the issue of motor selection, for instance, between the DC motor and stepping motor, but they often do not give concrete answers to specific problems. Moreover, it is preferable to have motors of similar dimensions for comparison purposes. Although there is a good selection of professional-quality DC motors to choose from, not as many types of stepping motors are available. The Portescap claw-pole stepping motor, with a diameter of 16 mm (see Fig. 1(c)), is one exception.

Meanwhile, deciding on the optimal gear reduction ratio requires using different criteria between the two types of motors. Figure 4 shows an experiment that uses the stepping motor with a 5-to-1 reduction ratio gear head and a DC motor with a 81-to-1 reduction ratio to drive a mechanism incorporated in a rubber finger. We concluded that a 9-to-1 gear ratio is optimal for this stepping motor when driven by a simple voltage source circuit. Theoretically, this ratio can be easily determined from the 'pull-in' characteristic curves of the motor, and the characteristics of the load. However, we must note that an arbitrary gear ratio cannot be selected from the motor manufacturers standard products, and we can only select a ratio close to the desired ratio.

On the other hand, it is known that the optimal ratio for a DC motor is given by $(J_L/J_M)^{½}$, where J_L and J_M are the moments of inertia of the load and rotor, respectively. The ratio for the above case is around 50. However, this value is based on the assumption that the load friction is negligible. Actually, since there is a considerable load similar to friction if a cover like a glove is used over the mechanism, the gear reduction ratio must be higher. We concluded that as tool for selecting the optimum gear ratio, the simulation technique mention above should be redesigned, and this can be a final-year project for the undergraduates.

Based on an overall evaluation, we concluded that a permanent-magnet DC motor with a precision gear train is the most suitable candidate for a sign-language robot hand. An alternative method would use a shape-memory alloy actuator. This method has promising features as long as it is designed and used properly. However, in order to realize the quick, natural movements of a human finger using thin wires of shape-memory alloy, we would need a technique for rapid heating and cooling of the wires.

Figure 4. Testing the miniature stepping motor and a DC motor for finger drive

9. Discussions and conclusion

The design of a sign-language robot hand was considered from two aspects: as a design lab for control majors, and as a faculty research project. Relevant technical and educational issues were discussed.

A non-human sign-language interpreter can prove useful in situations where one's privacy must be protected, for example, in litigation or when discussing personal medical issues with a physician. But when we realize that sign language is more than just an assistive means of communication for the hearing challenged, and in fact is a proper language, we discover broader social implications. For instance, we may, as a first step toward realizing a more barrier-free society, consider introducing sign language as an optional second-language subject in primary or secondary education. Although we are far short of qualified instructors to take this step today, certain technical aids can facilitate matters in this direction. For example, some researchers are already looking at animation systems for sign language. With the current system, however, one is able to perceive whole sentences, but individual words often escape the viewer's attention [2]. This can perhaps be improved with the use of stereoscopic (3D) glasses, but they tend to be uncomfortable and appear to be not so practical at this point. A robot hand capable of accurately displaying sign language, if developed, is likely to be free of this disadvantage.

We do not expect to see in the span of just a few years a robot hand with sign-language proficiency equal to that of human practitioners. It would be prudent to start out with the minimum design requirements, possibly those needed to achieve finger spelling. To this end, we examined comparisons of combinations of various types of actuators and mechanism based on our past studies and simulations. Obviously, more sophisticated expressions will be studied as research progresses[10,11].

What can be called 'language education engineering' can be said to have seen its beginnings when someone first used a tape recorder to practice a foreign language. Today there is a considerable number of software and hardware products for language translation available on the market, enough that the technological components that assist inter-language communication can justifiably be called an engineering field in its own right.

The technology associated with a robot hand that communicates in sign language, where mechatronics will naturally be a key element, will constitute a component of this field. This may require an entirely different kind of motion control from that employed in previous robotics, as seen for instance in automated assembly lines. Such an endeavor, based on information technology and the science of sign language, may also provide new clues for the direction in which communication between 'robo-sapience' and homo-sapience will take place in the 21st century (see Fig.5).

Figure 5 Information Technology as a user-friendly technology

10. References

[1] T. Kenjo, "Unique Continuing Engineering Education by Employment and Human Resources Development Organization (EHDO)," *8th World Conference on Continuing Engineering Education, Toronto*, pp.100-106, 2001.

[2] M. Terauchi, T. Matu-ura, Y. Nagashima, "Electronic Dictionary System Considering Sign Language Study," *IEICE Technical Report, Welfare Information Technology*, Vol.00, No.1, pp.7-10, 2000 (in Japanese).

[3] T. Kikuchi and T. Kenjo, "Distance Learning Applied to a Small Motor Laboratory –Insight into the Stepping Motor-," *Proc. 1999 IEEE Int. Conf. on Systems, Man and Cybernetics*, pp.259-264, 1999.

[4] T. Kikuchi, T. Kenjo and S. Fukuda, "Remote Laboratory for a Brushless DC Motor," *IEEE Transactions on Education*, Vol.44, No.2, CD-ROM Issue, 2001.

[5] T. Kenjo, T. Kikuchi and M. Kubo, "Developing Educational Software for Mechatronics Simulation," *IEEE Transactions on Education*, Vol.44, No.2, CD-ROM Issue, 2001.

[6] T. Kenjo, M. Terauchi et al., *Motor Controls Learned by Simulation and Experiments*, Nikkan-Kogyo Shimbun-sha, 2001(in Japanese).

[7] I. Kato, *Robot Hand*, Kogyo Chosakai Publishing Company, 1981 (in Japanese).

[8] P. Menzel and F. D'Aluisio, *ROBO-SAPIENCE: Evolution of a New Species*, MIT Press, 2000.

[9] H. Sugiuchi and T. Morino, "Co-operative Action of Dual Multi-finger Robots hand – Implementation of Dual Hand Synchronization–," *Proceedings on Robotics–Mechatronics*, 2001, 2P1-K5 (in Japanese).

[10] Y. Nagashima, K. Kanda, M.Sato and M. Terauchi, "JSL Electronic Dictionary and its Application to Morphological Analysis," Proceedings of the Human Interface Symposium 2000, pp.189-192, 2000 (in Japanese).

[11] K. Kanda, et al., "sIGNDEX V.1 & V.2 The Computerized Dictionary of Japanese Sign Language," Proceedings of TISLR (7th International Conference on *Theoretical Issues in Sign Language Research)*, p.195, 2000.