*Report on the Workshop*
**Trends in Teaching Robotics to UG/PG Students (TTR-12)**
December 22, 2012 (Saturday)
Indian Institute of Technology Delhi, New Delhi, India


by


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## 1. Preamble

The workshop on **Trends in Teaching of Robotics to UG/PG Students** has been conceived, mainly, to give directions to the faculty members teaching courses on Robotics, for effective teaching of the course offered to UG/PG students of Mechanical and Electrical Engineering Departments. The area is growing fast in India and there is a large demand for quality engineers. Hence, it is essential that the universities/colleges around the country find a minimum base that MUST be achieved to make those students ready to work with the subject of Robotics, be in industry or in higher studies.

In order to fulfill the above objectives, it was planned that we should learn what different faculty members of Robotics courses are teaching in their courses. In particular, it was hoped that we should be able to answer the following questions at the end of the workshop:

1. What are the topics, e.g., kinematics, dynamics, control etc. that should be covered in a typical UG or PG course on Robotics?
2. What kind of books should be used to teach a typical course on Robotics?
3. How software should be used to aid the teaching of Robotics?
4. What kind and how many experiments should be included in the course?
5. How much self-study learning aspect in the form of reading or making robots (say, for a competition) should be included?


Based on the valuable inputs from the participating faculty members we were be able to formulate a road map for effective teaching of Robotics in the country, so that our industries and academia benefit immensely.

## 2. Minutes of the Workshop

On December 22, 2012, workshop on **Trends in Teaching of Robotics to UG/PG Students** was held at IIT Delhi. The workshop was sponsored by CD Cell (QIP) and spearheaded by Prof. S. K. Saha. The aspiration of the workshop was to discuss and develop a curriculum on the Robotics course offered to UG/PG students at different engineering colleges in India. Focus was on how to attain synergy between the theory and practicality in robotics. Keeping these objectives, academicians from various institutions of India, book publishers, and research scholars shared the common platform.

The morning session started with the registration process at 9:30 A.M. Prof. S. K. Saha gave a very warm welcome to all the participants. At 10:00 A.M., the workshop started with a presentation by Prof. S. K. Saha (see Appendix I for complete program) in which he gave a bird's eye view on robotics course, i.e., sensors, actuators, DH parameters, kinematics, dynamics, serial and parallel robots, etc. He included that it was not possible to give the complete flavor to understand the "physics behind the mathematics" of robotics. Hence RoboAnalyzer was developed at IIT Delhi which could be used to understand "what basically is happening." Regarding the interfaces used by the robots Prof. Ashish Dutta *(faculty at IIT Kanpur)* briefed about the use of VAL-2 for programming robots. He laid more emphasis on projects, to understand the software used in robotics. Dr. Shubhendu Bhasin *(faculty at IIT Delhi)* agreed with Prof. S. K. Saha, that having kinematics, dynamics and controls in a single course would make the subject quite complex. He mentioned that each book has different notation of parameters which limits the smoother understanding of the subject. Adding a case study to the course and learning by demonstrations was emphasized by Dr. Shital S. Chiddarwar *(faculty at VNIT Nagpur).*

Dr. Sandipan Bandyopahdyay *(faculty at IIT Madras)* highlighted the difference between singularity and isotropy. He also described that mathematical demonstrations could be understood by virtual models using interactive and symbolic software like MATHEMATICA. Dr. C S Kumar *(faculty at IIT Kharagpur)* mentioned about the difficulty in performing real-time experiments, which require sophisticated equipments and the skilled manpower. He gave more emphasis to virtual labs and control system modules. In his view, simulation methods could be used in lecture classes. Moreover, before coming for classes, students could go through these virtual labs for better understanding. Mr. Vishal S. Sharma *(faculty at NIT Jalandhar)* agreed with the virtual lab concept.

Bond Graph modeling was explained by Dr. P.M. Pathak *(faculty at IIT Roorkee)* and Prof. Anand Vaz *(faculty at NIT Jalandhar).* Prof. Anand Vaz also pointed out that majority of the students lacked basic concepts in mechanics, which need to be bridged in a Robotics course.

According to Dr. M. Santha Kumar *(faculty at IIT Indore),* students generally think that "control" is an electrical part and not mechanical. Hence, special workshops should be there to understand the control aspect of Robotics, whereas the partition control and under-actuated system were explained by Mr. Vijay Prakash Eathakota *(faculty at IIIT Hyderabad).*

"Robo-Competitions can be a part of the course where small robots should be built to generate enthusiasm in students," quoted Mr. P. K. Rao *(from O.P. Jindal Institute of Technology, Raigarh).* His thought was supported by Dr. Amit Singh *(faculty at MNIT Jaipur).* Dr. Singh also said that it was better to have industrial approach apart from the mathematical approach. At the end of morning session, a nice arrangement of feast was there, where people interacted with each other.

Prof. S. K. Saha named some of the books followed in robotics including his own book "Introduction to Robotics" published by Tata McGraw-Hill. The in-house software "RoboAnalyzer" developed under the guidance of Prof S. K. Saha would act as an additional tool to understand the physics behind robots. The key features of the software were presented by its core developer, Mr. Rajeev Lochana C.G.. He also explained about the new features that were added recently to the software.

Dr. Sandipan Bandyopadhyay explained how extensive modelling and simulations using software have made the design and development of MaPaMan (Madras Parallel Manipulators) easier. Dr. C.S. Kumar gave an overview of virtual robotics lab developed as a part of MHRD initiative. He showed a demo of controlling a physical robot at IIT Kgp. from his laptop remotely.

Several book publishers also presented their views. Ms. Harsha Singh *(from Tata McGraw Hill, New Delhi)* told about the books which they are publishing on Robotics. She also shared that students show great interest and want to know more about Robotics, but it was difficult to find all the contents in one book.

Mr. S. Srivatsav and Mr. Sameer Gupta *(from Oxford, New Delhi)* told that currently they are publishing only one book on Robotics by Prof. Ashitava Ghosal (*faculty at IISc Bangalore*). They also told that people generally come up with research papers but not with the text books. It was emphasized during the session that faculty must write text books in order to give confidence to our students who otherwise feel that true knowledge lies outside India and leave the country at the earliest opportunity of higher studies abroad.

Today, the most common problem students faced is building a robot after taking the Robotics course. Keeping this in mind, more mathematical formulation, modeling and dynamic simulation are required and more emphasis on projects is required. Block diagram modes and practicals can be introduced to understand the concepts. Many software like Mathematica, MATLAB, VAL-2, Nastran, C/C++, RoboAnalyzer can be used to grasp the concept and increase the interest in robotics. Today, resource sharing is a great technique and can be used by different institutes to make the subject more fun oriented so that after completing the course student should feel "*Robot making is an art with fun and joy.*"

## 3. Suggested Course Structure

Based on the discussions in the workshop by the participants (see Appendices II and III), a typical course structure is given in Table 1. The same can be adopted by any university/institute in India:

Table 1: Typical course structure of a Robotics course at UG/PG level

- Course Title: "Robotics" or "Introduction to Robotics" or "Robotics Engineering"
- Discipline: UG/PG students of Mechanical/Electrical Engineering
- Level: UG 3$^{rd}$ and 4$^{th}$ year students, and M. Tech/Ph. D 1$^{st}$ year students

| SN | Lecture (3 hrs. module) | Lab. (2 hrs. module) |
|---|---|---|
| 1 | Applications; Types (Mobile, Parallel); Serial: Cartesian, Cylindrical, etc.; Social Issues | Demos of a real robot; Introduce Virtual Robotics Lab. in ADAMS or SimMechanics of MATLAB or RoboAnalyzer |
| 2 | Sensors and actuators used in Robots; Machine Vision | DH parameters of a real robot |
| 3 | Pose, DH Parameters, Homogenous Transformation | Forward kinematics in MATLAB/Mathematica |
| 4 | Forward and Inverse Kinematics | Inverse kinematics derivations |
| 5 | Jacobian: Velocity transformation, Singularity | Programming in MATLAB/Mathematica |
| 6 | Statics: Use of Jacobian | Find Jacobian, Singularity |
| 7 | Dynamics: Newton-Euler Recursive Algorithm, Simulation | Class Project 1 Presentation* |
| 8 | Euler-Lagrange Equations of motion/Formulation using Decoupled Natural Orthogonal Complements (DeNOC) | Control simulation (MATLAB, Simulink, SimMechanics, RecurDyn) |
| 9 | Kinematic design: Singularity, Dexterity, Isotrophy, manipulability | DC motor control set-up |
| 10 | Mechanical design of robot links | Programming of ER9 robot |
| 11 | Control: Definition, closed-loop algorithm, Hybrid position/force control; Non-linear control (must for EE Students) | Verify using RoboAnalyzer |
| 12 | Motion planning: Polynomial, Spline, etc.; Robot Programming like VAL-2 | Dynamics of 3R robot |
| 13 | Parallel Robots: Inverse and forward kinematics | Project 2 presentation* |
| 14 | Mobile Robots: Kinematics and control | Buffer class |

*Possible Class Projects: 1. Kinematic/Dynamic modeling, programming, and analyses of a robotic arm (say, an RP manipulator); 2. Modeling of an AGV; 3. Building prototypes using, say, LEGO kits

**4. Books**

It was suggested that a standard text book should be prescribed which the students must follow closely. Other books could be considered as supportive books for some topics which may not have been covered in the text book. Some of the good books used by the presenters are:

- Craig, John J., "Introduction to Robotics: Mechanics and Control," Prentice Hall, 2003 [Most of the presenters used this classical book]
- Saha, S.K., Introduction to Robotics, Tata McGraw-Hill, New Delhi, 2008
- Ghosal, Ashitava, "Robotics: Fundamental Concepts and Analysis," Oxford University Press, 2006
- M. Murray, M., Li, Zexiang, Sastry, S.S., "A Mathematical Introduction to Robotic Manipulation," CRC Press, 1994
- Tsai, L.W., "Robot Analysis: The Mechanics of Serial and Parallel Manipulators," Wiley Interscience, 1999
- Niku, S. B., "Introduction to Robotics: Analysis, Systems, Applications", Prentice Hall, 2001


**5. Software**

A course on Robotics must use one or more software not only to visualize the motion and characteristics of robots but also to analyze/synthesize/design robots for a given application (say, as class projects). Typical software which can be used are as follows:

- RoboAnalyzer (Developed by IIT Delhi; http://www.roboanalyzer.com)
- Virtual Labs. (Developed by IIT Kharagpur; http://vlabs.iitkgp.ernet.in/moodle/)
- MATLAB, its modules Simulink and SimMechanics (http://www.mathworks.com)
- Mathematica: Symbolic software (http://www.wolfram.com)
- Multi Bondgraph (http://bondgraph.org)
- ADAMS (by MSC software; http://www.mscsoftware.com)
- RecurDyn (by Function Bay, Korea; http://www.functionbay.co.kr)


**6. Other Aids**

- Class projects and presentations as listed after Table 1.
- Video of practical applications
- Industry visits
- ROBOCON competitions: A national-level competition held every year during the 1st weekend of March

## 7. Conclusions

The workshop was attended by 34 participants (including 14 from IIT Delhi who volunteered to help conduct the workshop) who appreciated the workshop very much (see feedback in Appendix IV and photos in Appendix V). Based on the day's discussions, the questions raised in the preamble were answered as follows:

1. What are the topics, e.g., kinematics, dynamics, control etc. that should be covered in a typical UG or PG course on Robotics? <u>See Table 1 of Section 3</u>
2. What kind of books to be used to teach a typical course on Robotics? <u>See Section 4</u>
3. How software should be used to aid the teaching of Robotics? <u>See Section 5</u>
4. What kind and how many experiments should be included in the course? <u>See Table 1 of Section 2, and Sections 5-6</u>
5. How much self-study learning aspect in the form of reading or making robots (say, for a competition) should be included? <u>See Section 6</u>

Finally, as per the suggestions given by some participants, this report will be sent to all participants and those institutes/colleges where Robotics courses are offered. Other suggestions like inviting industry people, etc. will be taken care off in future or will be passed on to those who would conduct such workshops in future.

## Acknowledgements

On behalf of IIT Delhi, I would like to thank all the participants to take the trouble of coming to IIT Delhi to participate in this workshop during the winter. I am grateful for their valuable inputs in the form of presentations and participation in the discussions. I also thank the Curriculum Development Cell of IIT Delhi for generously supporting the workshop. Last but not the least, I convey my sincere thanks to all organizing people, mainly, the students of Mechatronics and Programme for Autonomous Robotics Laboratories for their meticulous planning during last two months, and the staff of Mechanical Engineering Department and the hostels for their kind help (see Appendix III for complete list).

**22nd December 2012** (Saturday)
Block II - 422 (ME - Seminar Hall), Mechanical Engineering Department, IIT Delhi


**9:30 am - 10:00 am:** Registration
**10:00 am - 11:00 am: Session 1a**
    ☐ Presentations on what you teach & what needs to be done


**11:00 am – 11:30 am:** Tea Break
**11:30 am - 01:00 pm: Session 1b**
    ☐ Continuation of presentations on what you teach & what needs to be done.


**01:00 pm – 02:00 pm:** Lunch Break
**02:00 pm – 03:00 pm: Session 2**
    ☐ Books followed
    ☐ Software used
    ☐ Other aids used (like Class projects, Robocon, Technical fests etc.)


**03:00 pm – 03:30 pm:** PAR lab visit
**03:30 pm – 04:00 pm:** Tea Break
**04:00 pm – 04:30 pm: Session 3**
    ☐ Roadmap for future
    ☐ Closing Remarks
    ☐ Feedback

List of speakers and those who participated in the workshop is given below (arranged in alphabetical order of the last names):

| SN | Name | Organization |
|---|---|---|
| *Presenters* | | |
| 1 | Bandyopadhyay, Sandipan/Dr. | IIT Madras |
| 2 | Bhasin, Shubhendu/Dr. | IIT Delhi |
| 3. | Chiddarwar, Shital S./Dr. | VNIT Napur |
| 4 | Dutta, Ashish/Prof. | IIT Kanpur |
| 5 | Eathakota, Vijay Prakash/Mr. | IIIT Hyderabad |
| 6 | Kumar, C.S./Dr. | IIT Kharagpur |
| 7 | Pathak, P.M./Dr. | IIT Roorkee |
| 8. | Santhakumar/Dr. | IIT Indore |
| 9 | Sharma, Vishal S./Mr. | NIT Jalandhar |
| 10 | Singh, Amit/Dr. | MNIT Jaipur |
| 11 | Vaz, Anand/Prof. | NIT Jalandhar |
| *Other Participants* | | |
| 12 | Bajaj, Nikesh/Mr. | Aligarh Muslim University, Aligarh |
| 13 | Gupta, Sameer/Mr. | Oxford, New Delhi |
| 14 | Gupta, Vinay/Mr. | IEC, Greater Noida |
| 15 | Kamesararao, P./Mr. | O.P. Jindal Institute of Technology, Raigarh |
| 16 | Singh, Harsha/Ms. | Tata McGraw-Hill, New Delhi |
| 17 | Srivastava, Anmol/Mr. | Lovely Professional University, Jalandhar |
| 18 | Srivatsan, S./Mr. | Oxford, New Delhi |
| 19 | Sushil Prakash, Sushil/Mr. | MHRD, New Delhi |
| 20 | Varalakshmi, K.V./Ms. (on behalf of Dr. J. Srinivas) | NIT Rourkela |

The following students and staff have volunteered for various responsibilities of the workshop. Their services are duly acknowledged.

| SN | Name | Responsibilities |
|----|------|------------------|
| 1 | Ankush/Mr. | Proceedings, Representative for Aravali Hostel, Catering |
| 2 | Bhivraj/Mr. | Workshop kits, Registration Desk, PAR Lab. demo (KUKA-Exoskeleton), TA/DA |
| 3 | Boby, Riby Abraham/Mr. | Registration desk, Workshop kits, Demonstration in PAR Lab. (KUKA-Vision) |
| 4 | Chaudhary, N./Mr. | Venue facilities, Confirm workshop Banner placement, Contact security for opening of Block II gates on 22/12/12 |
| 5 | Hayat, Abdullah Aamir/Mr. | Minutes of the workshop |
| 6 | Kaushal/Mr. and Anuraag/Mr. | CD Writing RoboAnalyzer |
| 7 | Majid Hameed Koul, Majid Hameed/Mr. | Overall coordination, Proceedings |
| 8 | Mukesh/Mr. | Proceedings, Minutes of the workshop |
| 9 | Nandihal, Paramanand/Mr. | Accommodation in-charge, Representative for Vindyachal Hostel |
| 10 | Rajeevlochana, C.G./Mr. | Catering arrangements |
| 11 | Roy, Soumyajit/Mr. | Workshop kits, Registration Desk, Representative for Jwalamukhi hostel |
| 12 | Sharma, Mangal/Mr. | Preparation of workshop kits |
| 13 | Sunita/Mrs. | Coordinating with Mr. Chaudhary for Maintenance |
| 14 | Zubair/Mr. | Demonstration in PAR Lab. (KUKA- Exoskeleton) |

**Appendix IV: Feedbacks from Participants**

One of the most important feedback echoed by almost all presenters and participants was that

"**project-based (for example, building robots and developing hardware/software for competitions or otherwise) teaching should be emphasized so that students can not only understand the theory taught in the classes but also enjoy the subject. This will also build their confidence in the subject. Finally, it will also impart hardware skills which will enable them to become even an entrepreneur in case they find themselves not fit for an industry.**"

The related issues regarding the teaching of Robotics which must be considered are as follows:

- Strong mathematical background among students should be emphasized to make them follow and enjoy the subject of robotics. This was raised by several speakers.
- A laboratory course must be there along with the lectures either using real robots or using software. This will help students to grasp the subject better. At the same time skill will be enhanced.
- There were, however, concerns about how all can be fitted in a typical 42-hour (3 or 4 credits) course.
- In order to make the students and teachers aware of how effectively one can use the hardware and software components for the teaching of Robotics in India, some kind of "Guide to Robotics" or "Handbook to Robotics" can be made as e-material. The contents may include 'changing trends in robotics, new case studies, new aids and software, etc." In case some faculty members volunteer, it can be made as a joint activity. .

Other feedback were:
- Participants, particularly, the young faculty could get to know software like RoboAnalyzer and Virtual Labs, through this workshop which would enable them to make their course on Robotics better.
- Industry participations in such workshops should be encouraged to get their inputs for a Robotics course from industry perspective.
- More faculty members should have participated in order to get benefitted from such an important workshop. In future, more advertisements should be done to get more participations;
- In fact, to answer many unanswered issues and making more people aware of what has been discussed in the workshop, more such workshops should be conducted in future too.
- Robotics should be introduced even in schools as fun topic.
- Summary of the workshop should be documented and to be shared to all participants. It should be made available through a website for the benefit of all concerned. This will be done through http://www.roboanalyzer.com.

Photos of the workshop on "Trends in Teaching Robotics to UG/PG Students" held at IIT Delhi on December 22, 2012 (Saturday)