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MECHATRONICS CURRICULUM DEVELOPMENT IN AN EMERGING ECONOMY– THE CASE OF THE KNUST, GHANA.

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Abstract
The intent of this article is to review progressin mechatronics course developmentat the Kwame Nkrumah University of Science and Technology, Ghana,in light of global developments.Mechatronics synergistically combines knowledge from mechanical engineering, electrical and electronics engineering, and computer science to design modern products and systems. Over the past two decades ithas gained prominence in the educational and industrial sectors of many countries, and many universities have introduced mechatronics engineering at the undergraduate studies level. The primary disciplines involved in the design of mechatronic systems include mechanics, electronics, controls, and computer science. In this paper the authors review mechatronics course development in the Department of Mechanical Engineering of the Kwame Nkrumah University of Science and Technology (KNUST), Ghana. An extensive literature review is carried out, and the course structure at the KNUST is compared with mechatronics curricula in several foreign universities. Student and faculty mechatronics projects are then reviewed. The comparisons reveal that even though the KNUST experience is fairly new, on module by module basis it compares well with at least one foreign university. Another key finding is that there is a fast growing interest in mechatronics studies in Ghana, and through student projects the students learn to analyze existing technology, understand system functionality and then design and build fully functioning mechatronics systems. A natural outcome and recommendation of the study is that any local mechatronics programme such as the one at the KNUST must establish strong ties with local industries while seeking cooperation with global partner universities in order to make up for problems such as lack of research funds and other opportunities.

Keywords: Mechatronics, course, development, Ghana

1.0 INTRODUCTION

1.1 Research Purpose and the Evolution of Mechatronics

The purpose of this paper is to highlight progress in mechatronics course development at the Kwame Nkrumah University of Science and Technology (KNUST), by comparing the KNUST experience with some leading universities in the developed world.Mechatronics is a discipline that combines elements from mechanical engineering, electrical engineering, and computer science to design modern products and systems. It is in growing demand in educational institutions and industry in the wider world.This stems from the fact that very few mechanical devices can be found today that do not include electrical and electronic components and some

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type of computer monitoring or control (Masayoshi, 2002). This means to practice mechanical engineering in today's world, one must understand new ways for processing information and be able to utilize semiconductor electronics within products. Such systems, called mechatronics systems, deal with the design of products whose function relies on the synergistic integration of mechanical, electrical, and electronic components connected by a control architecture. Thus a mechatronic system designer must assemble analogue and digital circuits, microprocessors and computers, mechanical devices, sensors and actuators, and controls so that the final design achieves a desired goal, usually related to automation, such as Lima *et al.* (2002) have noted: that manufacturing systems automation is the key technological area of mechatronics and brings together a wide range of mechatronics technologies, including the hard technologies such as drivers, actuators and sensors and soft technologies such as software engineering and information technology as well as industrial robots and materials handling systems.

1.2 The Global Context

Given its cross disciplinary nature, mechatronics systems engineering today has gained much recognition and importance in the industrial world and many universities have established engineering degrees in mechatronics. Furthermore, the increasing applicationof automated systems of production, micro electromechanical systems, and sensor technology have accelerated the growth of mechatronics.

1.3 The African Context, and the KNUST Initiative

Only a handful of universities in Africa currently offer degree Programmes in mechatronics. They include Egypt, Ethiopia, Cameroon, South Africa, and perhaps only one or two more others, which may explain why even though mechatronics education is widely published in Europe and North America (Wright, 2002; Lyschevski, 2002; Giurgiutiun *et al.*, 2002; Meek *et al.*, 2003), there are very few publications focusing on Africa, and much less still, West Africa.The Department of Mechanical Engineering of the Kwame Nkrumah University of Science and Technology, Ghana introduced a one-semestercoursein mechatronics in its Mechanical Engineering curriculum in 2012. Since then, interest in this discipline is increasing very fast among both students and faculty.The KNUST's initiative one of the mechatronics pioneering efforts in West Africa. In this paper the authors present the KNUST experience in mechatronics education in Ghana. It describes the course in detail, highlighting its goals and structure, tools provided to the students, and challenges relating to attracting industry involvement. I addition the paper includes brief comparisons with the curriculum structures of mechatronics programmes in several universities in the industrialised world.

1.4 Aim

The aim of the study is to review progress in mechatronics course development at the Kwame Nkrumah University of Science and Technology, Ghana, in light of global developments.

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The objectives are to:

i. Highlight progress of mechatronics in the world, noting the driving forces.
ii. Highlight the structure of the KNUST mechatronics initiative, noting progress in supporting infrastructure, student and research projects, and any benefits so far.
iii. Highlight the structure of mechatronics initiatives in selected leading universities in the advanced world.
iv. .Compare the course structure of the KNUST mechatronics initiativeand the programme structure of mechatronics initiatives in the selected leading universities to draw conclusions.

2.0 RESEARCH PROGRAMME

2.1 Rationale and Research Questions

Mechatronics projects provide an excellent vehicle for certain benefits to students including the ability to practice the design concepts that they have been taught, while forming a strong foundation in mechatronics principles. The aim of the researchwas to present the KNUST experience in mechatronics education in light of world best practice.The objectives are to identify the benefits of mechatronics education, and to benchmark the KNUST experience against experiences in the industrialised world. To fulfil these objectives, a literature study was carried out to review publications relevant to the said objectives. The outcome of the literature search is an initial set of findings regarding the structure of mechatronics programmes in foreign universities. These were later compared with results from the KNUSTexperience to form the final conclusions regarding the level of development of the discipline at the KNUST.

The aim of the work was to answerthe following questions:

1. What are the major driving forces that motivate mechatronics development?
2. How are these dynamics playing out in Africa in general and Ghana in particular, especially at the KNUST?
3. What is the level of development of the discipline as compared with similar Programmes in other places?
4. What is the situation on the ground so far in terms of student and faculty projects?

The purpose of the above questions was to guide the literature search and case study.

2.1 Research Methodology

This work is an exploratory research guided by a set of research questions, as indicated above. The overall methodology followed in the work took the form of a literature review combined with a detailed case study of the KNUST experience focusing on course content and student projects.

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2.1.1Search and data gathering strategies

This research is essentially a qualitative case study. A systematic literature review was conducted using selected research databases. The search strategy involved first identifying the relevant data sources and key words. These sources included journals, conference proceedings, books, and articles from trade journals. The search was conducted by using a range of keywords and key phrases that could be relevant to mechatronics. Four foreign universities in Europe and North America with mechatronics programmes were identified in the literature for the purpose of comparingthem with the KNUST programme using a simple tabular format.The KNUST case studywas carried out to obtain greater insight into an African perspectiveof mechatronics, and it allowed clarification of Ghana-specific issues arising from the literature review. The main instrument used for the case study is personal investigation complemented by KNUST literature.

3.0 DRIVING FORCES AND OBJECTIVES

The plan to launch a mechatronics coursethatcould in the future lead to a full mechatronics programmeat the KNUST is motivated by several factors including the following:

3.1 Increasing Electronics Content of Mechanical Products

The initiative is a natural response to the observation that nowadays there are very few mechanical devices that do not include electrical and electronic components and some type of computer monitoring or control. The realisation dawns on every stakeholder,that to practice mechanical engineering in the 21st century, one must understand new ways to process information and be able to utilize semiconductor electronics within mechanical engineering products.

3.2 Student Interest,Yearning and Educational Motivation

Occasionally in the past students from the KNUST mechanical engineering programme worked on projects that required knowledge and interaction from different engineering fields. As time went by and this demand increased, itengendered the need for a course or curriculum that offers integrated systems engineering.The rising interest in mechatronics studies at the KNUST is evident by the increasing number of student projects in the Department of Mechanical Engineering that involving mechatronics. This is in consonance with trends in other universities worldwide (Vaughan*et al.*, 2008; Wright, 2000).

3.3 Opportunities to Improve Product and Process Design and Manufacturing

Faculty and students are encouraged to take a systems approach to the design and manufacturing function in order to be able tomodel and represent system functionality better to improve product and process design and manufacturing.

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3.4 Meeting Industry Needs in Ghana

The formal sections of Ghanaian industry are becoming more and more interested in manufacturing process and plant automationas well ascomputerized production. Demand is now higher than ever for multi-disciplinary engineers who have in-depth knowledge of mechanics, electronics, and computer programming, and how to synergize and leverage these for integrated product design, development, and manufacturing. The demand for such engineers with systems thinking and capability isincreasing, even though*mechatronics* as a term is still relatively unknown in Ghanaian industry.

3.5 Mechanical Engineering Developmentin Africa and the Wider World

Globally, as technology has advanced, computers and electronics are playing bigger and bigger roles in mechanical engineering systems in areas such as robotics, mechatronics, advanced manufacturing technology (Awono Onana *et al.*, 2014); in response more and more mechanical engineers and students are taking computer and electronics courses in order to strengthen their grasp on mechanical systems technology. Industry surveys worldwide consistently show that firms today expect practicing mechanical engineers to have strong computer science and electronics skills and to be able to apply these in practical ways in their day to day functioning as engineers (Giurgiutiu *et al.*,2005; Grimheden & Hanson, 2005).

3.6 Influence of Globalization

The demands of globalization mean that mechanical engineers must be able to adapt, operate and function well within a global context,with a firm grasp on mechanical systems technology to overcome the constraints usually imposed by national or regional idiosyncrasies.

3.7 Objectivesfor Launching the KNUST Mechatronics Initiative

The main objectives for launching a mechatronics courseat the KNUST are to provide the following:

a. Integrated systemsengineering education to equip Mechanical Engineering (ME)graduates with the necessary knowledge and skills needed for national and regional industrial development.
b. In-depth knowledge in the analytical, experimental, and computational areas of mechanics, electronics, mechanical and electronic control systems, and computer science.
c. Knowledge and skills to analyze, design, program, build, operate and maintain fully integrated mechatronics systems.
d. To develop in students the ability to communicate effectively within a multidisciplinary design team comprising electrical and electronics engineers and computer scientists working on a large with mechatronics project.

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4. 0 COURSE STRUCTURE AT THE MECHANICAL ENGINEERING DEPARTMENT (KNUST)

The mechatronics course at the KNUST is initially being developed by the combined effort of the staff of the mechanical engineering department, but will later receive contribution from the electrical and electronics engineering, and computer engineering departments. A team consisting of threefacultymembers developed the course in 2011, afterstudying curricula in North American and European universities.

4.1 Mechanical engineering department requirements

With respect to credits, the mechanical engineering department requirements are set at 88 credit hours with the structure divided into the five main fields: electrical and electronics, mechanics, computer science, control and instrumentation, and mechatronics systems, as described below:

4.2 Electrical and electronics engineering

This field includes electrical circuits, analog and digital electronics including logic circuits, power electronics, drive circuits, and electrical machines.

4.2 Mechanical engineering

This field covers statics, dynamics, vibrations, thermodynamics, heat transfer, fluids, Computer Aided Design (CAD), manufacturing, material science, machine design, hydraulic and pneumatic systems.

4.4 Control and instrumentation engineering

This field includes analog and digital control systems, robotics, automation, signal processing, sensors and actuators, statistics and quality control.

4.5 Computer science and engineering

This field includes microprocessors, microcontrollers and their programming, Programmable Logic Controllers (PLCs) and their programming, simulation, interface, and machine intelligence.

4.6 Mechatronic systems design

This field concentrates on the synergistic integration ofthe above areas for the analysis and design realization of fully functioning integrated mechatronic systems.

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5. 0 COMPARISON OF CURRICULUM STRUCTURES OFSELECTED GLOBAL UNIVERSITIES WITH THAT AT THE KNUST

Lyshevski (2002) has noted that curriculum design is crucial for success in mechatronics education. In general, the courses developed tend to reflect the needs of local industry, the individual backgrounds and interests of faculty members involved, student perceptions and interests, and availability of resources, particularly human and financial.

In this regard, and in light of research objectives (iii) and (iv), curricula at several global universities were used as benchmarksfor purposes of comparison with the KNUSTcourse structure. They are University of Linz, Austria (Mechatronik, 2003), Waterloo University, Canada (University of Waterloo and CSME, 2001), North Carolina State University (North Carolina State University, 2014), and the University of Glamorgan, Wales (Wilczynski *et al.*, 1998; Wright, 2000), as shown in table 1.

Table 1.Percentage of core mechatronics courses among several universities worldwide

Mechatronics Core component	**University and % structure of its mechatronics offering**				
	KNUST	Waterloo	NCSU	Glamorgan	Linz
Electrical	13	13	19	29	34
Mechanical	43	29	37	10	34
Control	10	17	10	20	9
Computer	10	24	24	15	11
Systems	24	17	10	26	12

In the above comparisonsfocus is only on the core mechatronics elements, i.e.the percentages given in the table include only the engineering courses taught at the indicated universities. The detailed curriculum for each university is analyzed and each course is categorized in one of the five main fields of study.For simplicity, the table combines related courses (such as analogue and digital control) into a single module. It can be seen that even though the KNUST experience is fairly new, on module by module basis (i.e. at each level) it compares well with at least one foreign university.

6.0 SUPPORTING LABORATORIES AT KNUST

With regard to supporting infrastructure, the mechanical engineering program has ten laboratories at its disposal to support a mechatronics programme. Only three of these laboratories are supported by other engineering departments, These are electrical circuits laboratory and electric machines laboratory(power laboratory) offered by the electrical engineering department, electronics laboratory offered by the computer engineering department. The Department's own facilities include a computer lab, hydraulics lab, process control lab, technical preparations lab, strength of materials lab, fluid mechanics lab, mechanics of machines lab and metrology lab.In addition to the above the Department is investing in a specialized mechatronics, automation, and controls laboratory, whichwill offer experiments that are focused on the design and analysis of fully integrated mechatronics systems. It will emphasize microcontrollers and microprocessors input/output interfaces through sensors and motors. The lab will be equipped with micro controllers kits, Intel 8085 kits, and Motorolla 68HC11. Programming interfaces will include assembly and the computer programming languages.The instrumentation aspect of the lab will contain different sensors and transducers such as temperature, optical, conductive, capacitive, and strain gauge sensors interfaced with processors and computers through data acquisition systems interfaced through dedicated software such as Matlab. The controls component of the lab will contain speed-and-position motor control kits, and complete pneumatic and hydraulic control units (which include servo drives andProportional-Integral-Derivative (PID) controllers) The automation aspect of the lab will containComputer Numerical Control (CNC) machines, a robotic system with conveyors, motors, and sensors, and PLC units.

7.0 STUDENT AND FACULTY PROJECTS

The mechanical engineering department at KNUST promotes and supports practical final-year student projects as a key graduation requirement. Students are encouraged to take up new projectsthat have significant mechatronics content and to make use of the principles of integration of mechanical and electrical engineering in designing mechatronics systems. They are also encouraged to do reverse engineering on existing mechatronic systems in order to understand the system dynamics and build a duplicate system. The emphasis is on the actual implementation and fabrication of complete mechatronic systems. Mechatronics projects provide both interesting and relevant hands-on experiences for a wide range of topics including design processes, basic mechatronics concepts, technical communication, and working in a group environment. This section presents a sampling of student and faculty projects and the tools provided to the students. The students learn to analyze existing technology, understand system functionality, and then design and build products. Five such products are a solar tracker, a CNC machine, a delta robot, a Tech arm robot,and a conveyor speed control and part counting system shown in Figure 1, Figure 2,Figure 3, Figure 4, and Figure. 5, respectively. In all the five projects students are able to build fully functional prototypes. All the elements of mechatronics (mechanical, electrical, control, programming, and system integration) are involved in the five projects.

7.1 Solar tracker

The solar tracker has light sensors at different positions around the solar panel frame. The readings of light intensity are compared and the frame is rotated towards the direction of higher light intensity till the sensors read the same light intensity (indicating that the solar panel surface is perpendicular to the sun). The rotation is powered by a linear actuator and a four bar link mechanism. The whole system is designed to power the pump of a garden water sprinkler.

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Figure 1. Solar tracker

7.2 Three-axis CNC machine

Another project is a 3-axis CNC milling machine,shown in Figure 2.This machine can automatically cut out a product from a raw material when given the necessary input by a computer. The milling tool is held in place by a tool holder capable of motion in three mutually perpendicular degrees of freedom relative to the workpiece. The machine is designed to mill patterns from wood. Such machines, though in great demand, are all imported into the country. Building CNC machines locally would give a huge impetus to the mechatronics programme at the KNUST.

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Figure 2. A 3-axis CNC Milling Machine

7.3 Delta Robot

The delta robot uses parallelograms in the design of the legs in order to keep the orientation of an end effector that has three degrees of translational freedom (Figure 3). Three motors control the rotation of the three legs, transforming these rotations into a specific pose.

Figure 3. Delta robot

7.4 Wearable Robot Arm

The fourth artifact is essentially a link mechanism designed to mimic the movement of the human hand from the shoulder to the finger tip, with the trunk acting as the ground link. The robot arm project was in two parts: The wearable arm and the standalone arm. The wearable arm consists of flat links that are strapped to the human arm of the user. The joints have sensors which tell the current orientation of all the flat links of the human arm in space. The stand-alone arm contains stepper and servo motors at each joint which act as actuators (Figure 4).

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Figure 4: Wearable Robot Arm

7.5 PLC Conveyor Speed Control and Part Counting System

In this work a Programmable Logic Controller (PLC) is used to automate the counting of objects on a moving conveyor, the PLC serving as the heart of the system. The sequence of operation is designed by a ladder diagram and the programming is done using the ISPSoft_V1.03 software. A sensor plays a vital part in the scheme as an input signal transmitter for the Programmable Logic Controller (PLC). The sensor detects the passing object while the machine operates. The input signal sent from the sensor to the PLC is displayed on a computer monitor. The devices controlled by the PLC are the motor, sensor, and a Variable Frequency Drive (VFD), responsible for conveyor belt speed variation (Figures 5a and 5b).

To further strengthen student projects in the future, links will be sought with local industry in order to tackle projects that have a bearing on real-life problems.

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Figure 5a: PLC Conveyor Speed Control and Part Counting System – Actual System

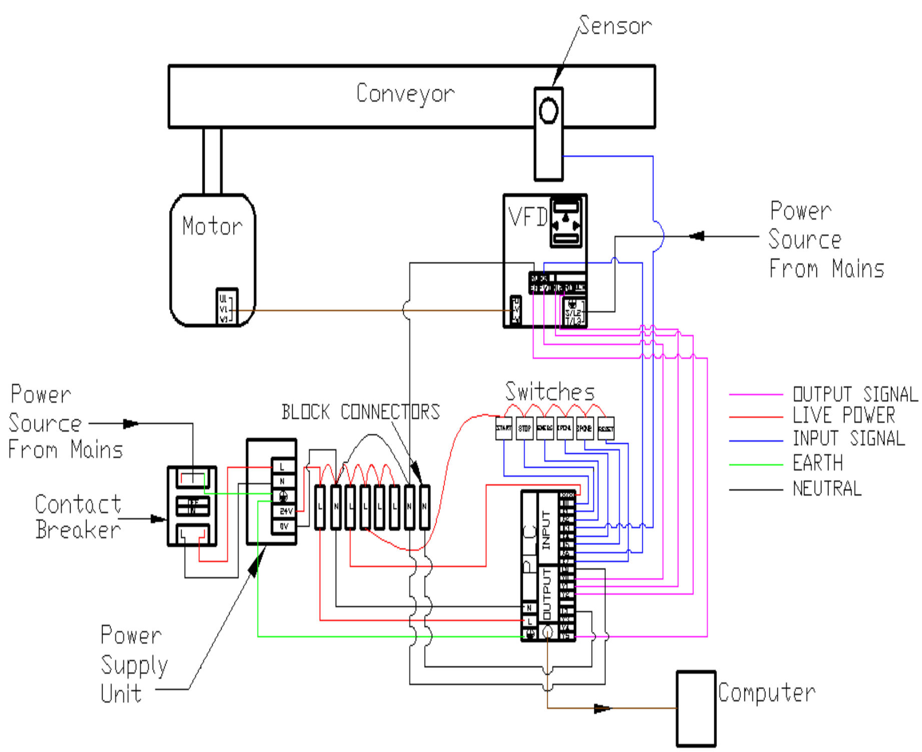

Figure 5b: PLC Conveyors Speed Control and Part Counting System – Wiring Schematic

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8.0 CHALLENGES

Challenges in developing a successful mechatronics programmeat the KNUST include:

i. The size of the *production automation and the design and manufacturing industry*in general in Ghana and West Africa is relatively small.
ii. Nearly all industrial technology used in Ghana is imported and therefore there is a lack of design and manufacturing support base to drive fast development.
iii. Research in mechatronics is virtually non-existent since no other local university offersany education in mechatronics.
iv. Since mechatronics is an integrated field of engineering with a strong emphasis on real-life applications, the absence of a strong industrial foundation in Ghana undermines the ability to expand fast.

These obstacles may be overcome by:

i. Finding ways to increase cooperation with local industry.
ii. Establishing exchange programs with foreign universities in order to benefit from technology transfer and learn from their experience. Efforts are being made in this direction.

9.0 CONCLUSION

Advances in actuator and sensor technology, solid-state devices, integrated circuits, computers and information technology, microprocessors, digital and optical signal processing, computer-aided-design tools and simulation software, have brought new challenges to the profession of mechanical engineering and related industry. As a result, many engineering schools have revised their curricula to reflect these trends and to offer the relevant courses such as mechatronics, which is a highly multidisciplinary concept requiring contribution from several engineering disciplines. In response to these global trends and driving forces, the KNUST is nurturing a mechatronics initiative which seems to be doing fairly well.

The major driving forces motivating mechatronics developmentat the KNUST have been identified to be the increasing electronics content of mechanical products, increasing student interest, yearning and educational motivation, opportunities to improve product and process design and manufacturing automation, meeting industry needs in Ghana, trends in engineering education development in Africa and the wider world, and by extension, the influence of globalization.

At the KNUST these dynamics are playing out in the form of a desire for an integrated systems engineering education to equip mechanical engineering graduates with the necessary in-depth knowledge in the analytical, experimental, and computational skills needed to analyze, design, program, build, operate and maintain fully integrated mechatronics systems for national and regional industrial development. There is now a fast growing interest in mechatronics studies in

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at the KNUST and through group projects student learn to analyze existing technology, understand system functionality and then design and build fully functioning mechatronics systems. Added to these is the determination to develop in students the ability communicate effectively within a multidisciplinary design teams. Results have shown that even though the KNUST experience is fairly new, on module by module basis its overall content compares well with at least one foreign university.

Thiswork demonstrates that while it is generally believed that beginning engineering students are usually too inexperienced to handle mechatronics concepts, the basic elements of the topic can easily be grasped by undergraduate students.Mechatronics is applied engineering and is heavily oriented to industry. It has been reported in the literature that in places where attempts to introduce the mechatronics only resulted inpartial success, the reasons for failure are due to the absence of short, medium and long-term strategies focused on industry. Therefore, mechatronics education at the KNUST must seek to establish this emphasis on industry. Furthermore, post-graduate programmescould be established to energize research and accelerate the mechatronics momentum in Ghana, West Africa and indeed Africa. With a well-developed curriculum, advanced laboratories and experienced staff, The KNUST will be able to establish a strong programme.

10.0 REFERENCES

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