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An Autonomous Robot for Casing Cutting in Oil Platform Decommission

Xiaojie Tian, Yonghong Liu, Rongju Lin, Pengfei Sun and Renjie Ji

College of Mechanical and Electronic Engineering, China University of Petroleum, Dongying, Shandong, 257061, China

Tianxj20050101@163.com; liuyh@upc.edu.cn; 1440644797@qq.com; 774580106@qq.com; jirenjie@upc.edu.cn

Abstract

The paper designs and develops a casing cutting robot for the platform decommission. This robot can achieve the sea-bottom casing reclamation duties required by the environment protection acts related to decommissioning of offshore oil plants. The objective of this research work was to investigate and explore the casing cutting robot model for the platform decommission. A 2-linear axis cutting robot is prototyped and a test bench is designed in the laboratory for the research. A surface control system provides remote control functionalities for the operator to command signals and automatic sequences. The robot control system based on Programmable Multi-Axis Controller (PMAC), which makes it easier to be operated. Moreover a Human Machine Interface (HMI) is developed to monitor and control the cutting process conveniently. The laboratory test results show that the robot system developed is very usable and it is working satisfactory for the casing cutting.

Keywords: *cutting robot; manipulator; control system; casing; electric arc*

1. Introduction

When the offshore petroleum platform reaches the end of their production lives, the structures and equipments need to be decommissioned. As the offshore petroleum industry has developed rapidly, more and more platforms are abandoned. Since 1947, over 2200 structures have been removed from the Gulf of Mexico [1-3]. In particular, it was required that, the seabed was free of any residual structures up to 15ft below the seabed surface. Cutting tools are important during platform decommissioning. The traditional cutting tools, including the explosives, chemical cutters, abrasive water jet cutter, radial cutting torch, diamond wire cutter and mechanical cutter, are in use for the subsea structures [4-6]. In particular, explosives and water jet cutter, disseminate large quantities of pollutants in the seaduring cutting process [7]. The cutting operations has evolved and become more stringent in the areas of health, safety, ease-of-transport and storage, precision and controlled cut.

It is necessary to develop an intelligent cutting robot for the casing cutting to realize remote control at surface and automatic cutting. Van Henten *et al.*, developed an autonomous robot for harvesting cucumbers in greenhouses. The robot is composed of the autonomous vehicle, the manipulator, the end-effector, the two computer vision system. It has seven

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degrees of freedom and can pick cucumber quickly and exactly [8]. Molfino and Zoppi proposed a robotic system for underwater eco-sustainable wire cutting. It used a diamond wire saw to accomplish the dismissing of off shore oil pants and worked satisfactory in the North Sea [9]. Thuot *et al.*, designed a submersible grinding robot to automate the dam gate metallic structure repair process. They developed a 3-linear axis grinding robot prototype and designed a test bench for the study of underwater grinding process [10]. Jang *et al.*, studied on human robot interaction technology using a circular coordinate system for the remote control of the mobile robot. And they also configured and tested a smart phone environment that can control the robot [11]. Kumar *et al.*, illustrated the development of a continuous monitoring system in assessing the support performance for safer and smooth operation of roof supports in these working under different geo-mining conditions [12]. Song *et al.*, researched the multi-robot open architecture of an intelligent CNC system based on parameter-driven technology. The CNC system capable of distributed processing of decision making and extraction of task information provides a premise for intelligent control and flexible operation [13].

The cutting robot presented in the paper is developed in response to the casing cutting and increasing environment protections. It consists of a cutting head operated by the control system and based on the electric arc cutting technology to sever casing. The following section descripts the robot working environment. The third section describes the robot design specifications. The fourth section gives the system integration and experimental trials with the robotic system prototype. And conclusions and future researches are discussed in the last section.

2. The Working Environment of the Robot

The decommission of offshore structures is a severing intensive operation. Especially, the structures below mudline are more significant to be removed, such as multi-string conductors, piling, and skirt string. All wellhead and casings are required to be removed to a depth at least u15ft (5m) below the mudline [14]. As shown in Figure 1, casings are driven into the seabed and need to be cut at a minimum of 15ft below the mudline, pulled and removed from the seabed, which would not become an obstruction to other users of the seafloor. The robot system presented is conveniently operated with little size, which is very suitable for the inner cutting. During cutting operation, the cutting tool environment, is deployed by the robot system and placed in casing interior. Through remote control at surface, the robot can complete the cutting process.

The originality of the system relies in combing and improving known and cooperating technologies, namely: electric arc cutting and sub-bottom operation with robot-based tools and remote monitoring and control. The electric arc cutting technology can cut high strength and electrically conductive material by the effect of high temperature and pressure produced during electric arc generating process. This technology cannot produce cutting forces, contact forces, knives breakage and vibration. The decision process took advantage from different kinds of virtual prototyping and simulation techniques that allowed the validation of the analyzed solutions at the subsequent design stages, as decision support and performance verification.

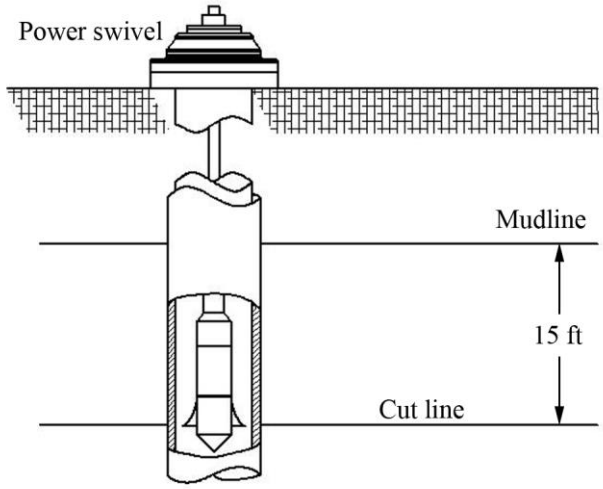

Figure 1. Schematic of cutting system below mudline

3. Robot Design Specifications

An innovative development in casing cutting methods is the electric arc cutting robot. Its main objective is to maximize operating safety and efficiency of casing cutting operations. The electric arc cutting tool employs tool electrodes producing high pressure and temperature arc to cut casing, eliminating the need to use dangerous chemicals or explosives, resulting in a safe and efficient cut with no flaring or debris left in oil well. The robot should be able to be operated under the adverse conditions. The cutting robot should be able to move autonomously in the casing. The robot should be able to detect the casing inner wall and feed tool electrode to generate electric arc. The robot should be able to detect the discharge status in real time and determine consumption of tool electrode. The manipulator should have a kinematic design such that it allows for cutting casing. And it should position the cutting point and center the cutting tool. Finally, the cutting robot should be transported easily and have a precision controlled cut.

3.1 Manipulator

The cutting manipulator, which works in sub-sea, is shown in Figure 2. Its overall shape is cylindrical and slim, which is convenient to be trapped into oil well. It mainly includes electronics section, transmission section and cutting head. There are anchors between rotator spindle and electronics section, which is deployed to keep the tool centralized and free from rotation during cutting operation. The electronics section houses driving motor and varies electronic equipments. The transmission section is responsible for transmitting power signals to the cutting head by the ball screw mechanism. The cutting head comprises the tool electrodes that can generate discharge arcs with casing. The tool electrode can be fed on continuously and exchangeable when used up. The prototype of cutting manipulator is designed as shown in Figure 2(b). It can be seen that there are three tool electrodes on the cutting head, which ensures the reliability and efficiency of cutting operation.

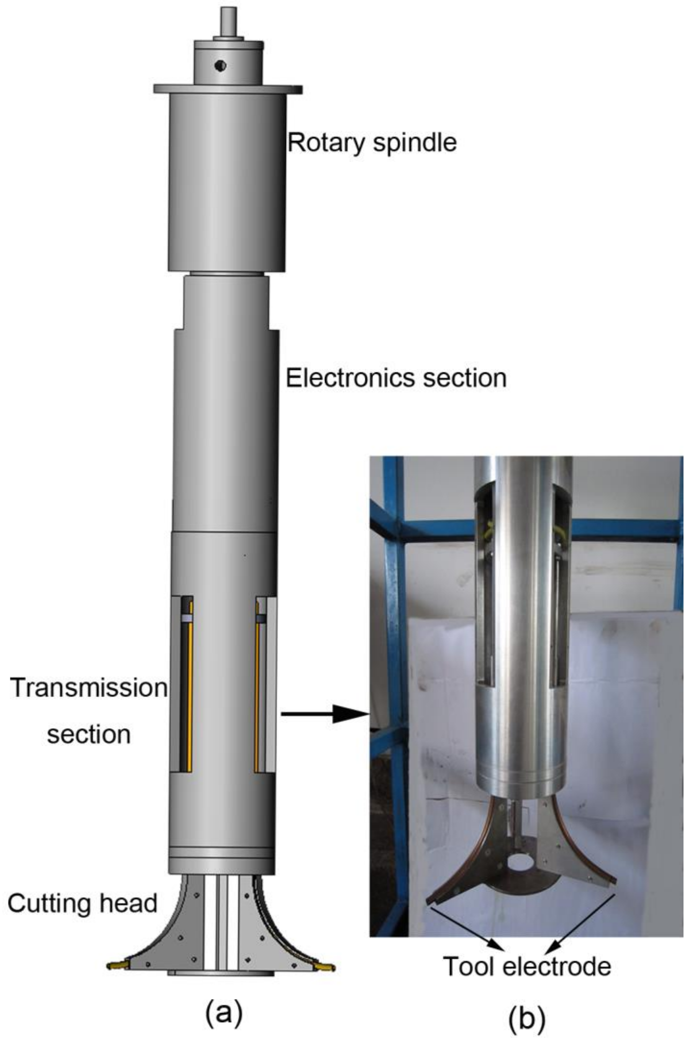

Figure 2. Mechanical manipulator of the cutting robot

The cutting mechanism is very simple. The tool electrode is fed toward into contact with the casing wall as the power section anchors the cutting robot in the casing. The cutting head is rotated while electric arc is generated. Therefore the steel is removed under the effects of electric arc. As a result, a very clean cut is achieved. The resulting cut does not flare or otherwise change the shape of the casing.

3.2 Control and monitoring system

The sub-sea manipulator is positioned in the main electric enclosure and has all onboard electrical equipment connected to it. Surface and sub-sea units are connected through fiber optical cables. The surface control system provides remote control functionalities for the operator to command signals and automatic sequences. The operator can launch and the control system can execute cutting operations autonomously. The success of the remotely operated robotic platform highly depends on the effectiveness and reliability of the electric arc cutting process. The control system hardware is spread in a surface control unit, including a control computer, control panel, a surface to sub-sea interface and data acquisition and monitoring system.

The core of control system is a Programmable Multi-Axis Controller (PMAC) [15], which is from the Delta-Tau Company and as the main motion control and data processing unit. It also can drive many servo motors simultaneously, and give commands, receive instructions and respond to signals. PMAC can communicate with an industrial computer, which allows the operator to monitor and command instructions to the robot during cutting operation. The robotic control system is shown in Figure 3. The automatic cutting operation involves on-off control, position control, tool electrode motion control, emergency mode control and supervision mode control. Through different function blocks, the system is integrated and divided into certain cooperation modules. There are two modes of control panel and Human Machine Interface (HMI) to operate the cutting robot.

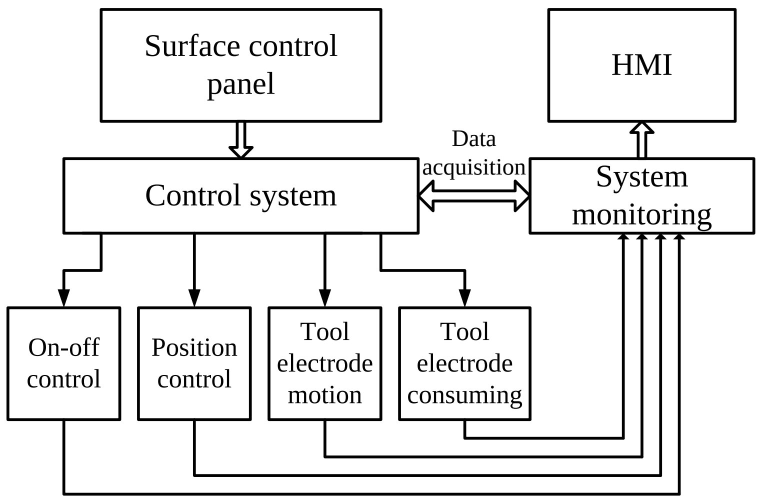

Figure 3. The block diagram of control system

The sub-sea manipulator is mainly composed of two different axes: one providing the feeding movement, the other providing rotating movement. Each axis is closed-loop controlled to ensure proper operation. The control strategy is based on hardware control loops and software control loops, which are real-time processes running on an industrial computer. The control flow of cutting operation is shown in Figure 4. The cutting manipulator is deployed to the oil well by the drilling pile on the platform. When the robot is up to the designated position, cutting tool would be in stand-by status and robot would receive signals. When the position is appropriate, the anchor would work and locate the cutting too in casing. And then the robot would execute the cutting operations and all the sequence is automatic. Operator can monitor and control the whole cutting operation on platform. At the end of cutting operation, the robot would stop working and the cutting tool is in standby status. The cutting tool would be ready to travel to the surface.

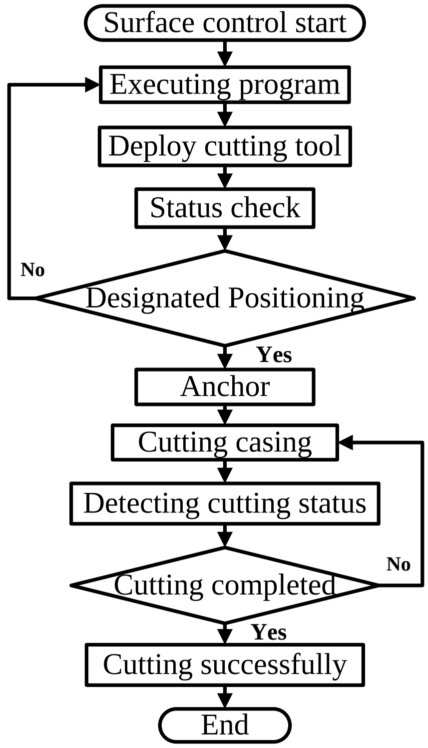

Figure 4. Control flow of casing cutting operation

3.3 HMI

Information on the advancement is visualized continuously on the operator interface and a friendly HMI with the characteristics of strong interaction and easy operation is designed, as illustrated in Figure 5. There are four main screens on the HMI, including tripping in screen, centralizing screen, cutting screen and alarm screen. Also each main screen contains many sub-screens to displays various states and parameters. Figure 5 displays the cutting screen during robot cutting process. The parameters monitored are position, feed velocity, rotating velocity, cutting current and cutting voltage. The tool electrode consumption also can be achieved easily from the screen. The robot system can be operated through HMI [16]. The motor velocities, cutting current, cutting voltage and frequency can be set manually. Before cutting operation, operators can choose the time minimum cutting mode or tool consumption minimum cutting mode. They also can configure the PMAC. An alarm screen is necessary for the monitoring. When the emergency is emerging, the alarming screen would change red color to remind the attention of operators. The whole cutting operation would be stopped. Only after the operator has checked the emergency and solved the problem, the robot can resume the automatic cutting or request further diagnostics or specific actions. The current and historical cases are saved in the memory, which could be read on the alarm list screen.

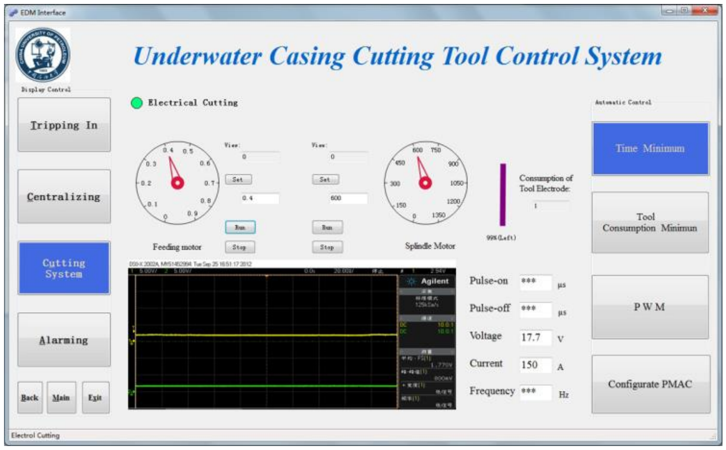

Figure 5. Main screen of the HMI

4. System Integration and Laboratory Test

The prototype of the cutting robot is established in laboratory as shown in Figure 6. These include the mechanical manipulator, control cabinet, power supply, computer and HMI. On the right, a servo motor on the top can drive the cutting head rotating in the casing. And the tool is placed inside the casing. The control cabinet integrates with the control unit, data acquisition and processing unit, transaction modules and communicate unit. There are a series of push-buttons on the control panel, which includes start button, stop button, close button, emergency shutdown button and current/voltage indication. The computer on the left is responsible for communicating with the control cabinet and providing the real-time data during cutting process. Operators on the surface can monitor the cutting robot status and dialogue with robot in any time through the HMI. Moreover the robot can be controlled by many computers at the same time. The initial operating mode of the cutting robot is automatic. If the robot would be operated manually, it needs to change the operating mode into manual operating.

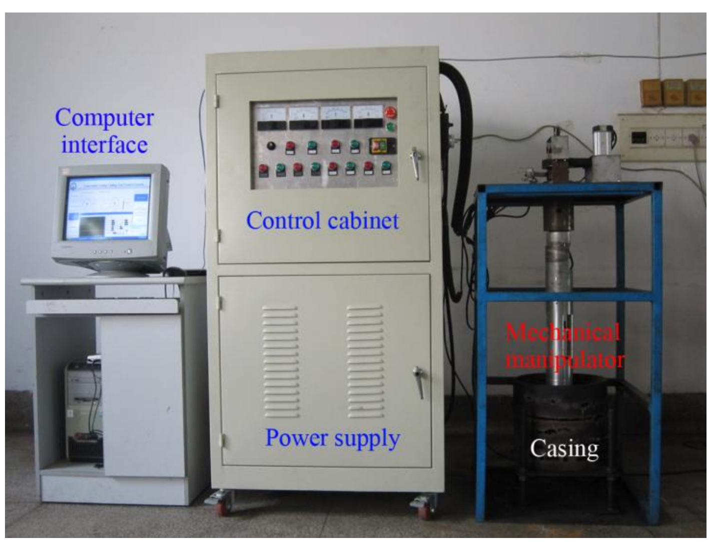

Figure 6. Prototype of the cutting robot in laboratory

The tests on the cutting robot have been carried out on the prototype in the laboratory. A section casing of 13 3/8 inch was used to represent all typical pile sections present in offshore platform. Its inner diameter is 339.72mm and wall thickness is 10.92mm. The tool electrode employed in the test is tungsten, which has very high melting point, high boiling point, high thermal shock and better spark erosion resistance. Therefore, it can reduce the consumptions of tool electrode and increase the service life. The cutting unit tested had the final design, progressively tuned on the base of the test results; it was instrumented and controlled using the same operation flows and schemes in the final machine. The aim of the tests was to confirm all decisions on the cutting related parameters and optimize the design of the mechanical unit and control system.

Figure 7 provides an example of the laboratory test while conducting a cut in casing. Once initiated, the robot would drive tool electrode feeding toward to the casing wall. When the distance is up to the discharge gap, electric discharge will be produced. It is clearly in Figure 7(a) that the electric arc has a long penetrating and has enough energy to remove materials. Next, the robot would drive the cutting head rotating in a circular. At last, the casing would be severed under the effect of high temperature and pressure of electric arc. The operator can monitor the cutting status from the HMI during the cut process. He also can adjust the motor speed and various control parameters in real-time and make decisions to emergency cases.

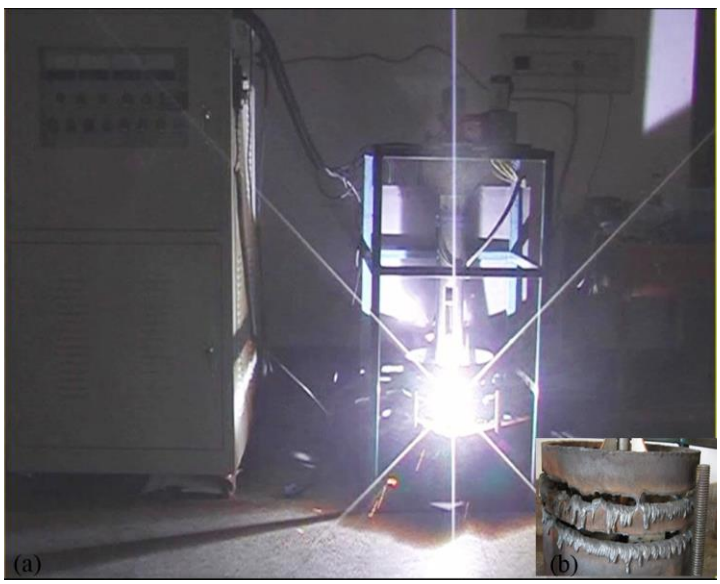

Figure 7. Cutting process and the results

The whole casing cutting operation lasts for about 15min and the test results can be achieved from Figure 7(b). The 13 3/8 inch casing was severed easily by the cutting robot in a short time. The cutting process was completed perfectly under the precision control and monitoring system. The cutting slots produced are net and smooth, but there is some dross on the cutting kerfs. The fine and coarse cracks on the cutting kerfs are not found. This is because that the tool electrode is not contacted with casing and any mechanical forces are produced. The cutting robot is flexible in its operating characteristics to overcome many dimensional and material defects of different casings. And with the use of the electric arc cutting robot, regulatory agency permits are not required eliminating many expenses related to marine life survey, fish kills and concern for endangered sea environments.

5. Conclusions and Future Research

This paper reports on a modular concept of an autonomous robot for the casing cutting in oil platform decommission. Building such a robot is not just a matter of choosing a suitable mechanic structure but also a precision control system. We have shown that the automation of the casing cutting requires the adoption of a new high efficiency control system and a data acquisition system.

(1) An electric arc cutting robot model has been proposed. We designed a slim and simple mechanical structure, which contains the cutting head, driving section, electronic section and transmission section. The mechanical manipulator satisfied stability and motion accuracy.

(2) The robot control system is developed based on the PMAC controller, which can drive many axes simultaneously. And the HMI is designed for monitoring and controlling from the surface in real time.

(3) A test bench is established in the laboratory for the cutting robot. The test results show that the cutting robot has efficiency and very good cutting, and no pollution to the environment.

(4) Future research will therefore focus on improved hardware and software for 3D image processing and field test is very necessary for the cutting robot system.

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Authors

Xiaojie Tian

She was born in Shandong, China, in 1985. She received her B. S. and M. S. degree in Mechanical Engineering from China University of Petroleum in 2008 and 2010 respectively. Currently, she is a Ph.D. candidate in Electromechanics Engineering in China University of Petroleum, China. Her recent research interest is the casing cutting robot system.

Yonghong Liu

He was born in Anhui, China, in 1965. He received his Ph.D. degree in Mechanical Manufacture from Harbin Institute of Technology, Harbin, China, in 1996. He is currently a professor and doctoral supervisor in College of Mechanical and Electronic, China University of Petroleum, China. His current research interests include EDM of ceramics, expansion sand screen for sand control and control system of subsea drilling equipments. He is a member of China Nontraditional Machining Committee and Nontraditional Machining Association of Shandong Province. He is Prominent Young and Middle-aged Specialist of Shandong Province and selected in New Century National Hundred, Thousand and Ten Thousand Talent Project.

Rongju Lin

He was born in Fujian, China, in 1988. He received his B. S. degree in Machinery Design and Manufacturing and its Automation from China University of Petroleum in 2010. Currently, he is a postgraduate student in Mechanical Engineering in China University of Petroleum, China. His recent research interest is numerical control system of casing cutting tool.

Pengfei Sun

He was born in Shandong, China, in 1990. He received his B. S. degree in Machinery Design and Manufacturing and its Automation from Yantai University of Petroleum in 2011. Currently, he is a postgraduate student in Mechanical Engineering in China University of Petroleum, China. His recent research interest is the investigation of casing cutting tool and manufacturing.

Renjie Ji

He was born in Shandong Province, P.R. China, in 1982. He received his B. S. and M. S. degree in Electromechanics Engineering from China University of Petroleum in 2005 and 2007, respectively. Currently, he is a Ph.D. candidate in College of Electromechanical Engineering in China University of Petroleum, China. His recent research interest is electrical discharge machining of engineering ceramics.