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Nikola Tesla and Robotics

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Abstract: The paper analyzes some of Tesla's works and his most remarkable views concerning the problem of formulating theoretical bases of automatic control. As a tribute to Tesla's work on remote control of automated systems, as well to his (at the time) far-seeing visions, special attention is paid to solving complex problem of control and feedback application. A more detailed discussion of the way and origin of formulating theoretical bases of automatic control are given. Besides, in more detail are presented the related pioneering works of Professor Nicholas Bernstein, great Russian physiologist who formulated the basic rules of the self-regulating movements of the man. Bernstein has achievements of highest scientific significance that has been in a direct function of identifying and proving the priority of his pioneering contributions in the domain of feedback, i.e. control and principles of cybernetics.

Keywords: Nikola Tesla, robotics, remote control.

1 Introduction

Nikola Tesla (1856-1943) is one of the giants of human intellect and the man whose research marked the end of the 19th and the beginning of the 20th century. Tesla's personality and scientific mind have become legendary thanks to his capacity to ingeniously solve most complex technical problems. His projects were more of an R&D character and, from a commercial point of view, often risky. Being obviously far ahead of his time and not skilled in making his projects commercially successful, Tesla was at the same time uncomprehended by potential investors and admired by intellectuals. With his visionary ideas, daring and risky research projects, Nikola Tesla has given an immeasurable contribution to the development of a number of technical disciplines. We would like to show that Tesla has also given an extraordinary contribution to the development of scientific thought in the domain of Robotics and automatic control. By analyzing Tesla's works, comments and scanty texts testifying of his ideas and results, we will show that Tesla can be rightly considered as one of the pioneers of world robotics, a man who have foreseen an unimagined development to this discipline.

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2 Tesla on the Future Achievements in Robotics

Tesla's pioneering work in robotics is noteworthy. He was inspired by Rene Descartes (1596-1650), and especially with his "*Discourse on Method*" [1] where it was constructed a mechanistic philosophy of the soulless machine. Taking himself as a model, Tesla often thought of, and in his visionary predictions indicated, the future achievements in robotics. Still in his early youth's reflections about everyday phenomena, Tesla traced his systematic approach to the analysis of the human environment. Based on the conclusions he had arrived at, he formulated a theory that our every spiritual vibration, thought, feeling or voluntary action have their cause in the external phenomena and impressions which, most often, because of the lack of training, we do not register them in all their richness and diversity. He stated that all living beings are automata driven by external impulses, and this eventually inspired him to construct an automaton, which, by analogy to the human body, would have means for the motion, direction, and sensitive organs like eyes to get impression of the outside world. In relation to this Tesla said ([2]; pp.31):

(a)* [2] *"....I have by every thought and act of mine, demonstrated, and does so daily, to my absolute satisfaction that I am an automaton (the word robot had not been coined yet) endowed with power of movement, which merely responds to external stimuli beating upon my sense organs, and thinks and moves accordingly...."*

Especially interesting is the following statement [3]:

(b)* *"Obviously, to put into practice this idea, it would be possible to construct a machine that would have the arms and legs, and which would walk in an upright position, but this would additionally complicate the task and make it more complex."*

By this, Tesla intuitively heralded the age of humanoid robotics, the field that is presently in the state of greatest scientific and technological expansion in the world, with the unimagined future possibilities. Obviously, he thought of constructing an automaton which would be a man's mechanical counterpart, and which would react to the external stimuli in a human-like manner, but, of course, in a more primitive way. He concluded such an automaton would have to be equipped with driving elements, control organs, and with one or more sensors for adapting to the external environment. Such a machine, as conceived by Tesla, would realize its movements like living organisms do, and would possess all main mechanical characteristics or properties of living beings. He concluded that some properties of living beings should not be copied. This is, first of all,

[2] (a)*, (b)*, (c)*, (d)*, (e)*, (f)*, (g)*, (h)* and (i)* In this way the personal statements of N. Tesla, found in the literature [1, 2, 3, 6], were designated.

related to the possibility of growth and propagation. It would be necessary that the automaton could perform all duties and tasks the same way as intelligent beings do (so spoke Tesla). In order to realize this, it would be necessary to create a certain element equivalent to human brain, which would control the motion and behavior of the automaton, as well as stimulate the appropriate reactions (based on the knowledge, experience, and reasoning) in dependence of the concrete situation.

In this sense Tesla stated ([2], pp.31):

(c)* *"With these experiences it was only natural that, long ago, I conceived the idea of constructing automaton which would mechanically represent me, and which would respond, as I do myself, but, of course, in a much more primitive manner, to external influences. Such an automaton evidently had to have motive power, organs for locomotion, directive organs, and one or more sensitive organs so adapted as to be excited by external stimuli. This machine would, I reasoned, perform its movements in the manner of a living being, for it would have all of the chief mechanical characteristics or elements of the same. There was still the capacity for growth, propagation, and, above all, the mind which would be wanting to make the model complete. But growth was not necessary in this case since a machine could be manufactured full-grown, so to speak. As to capacity for propagation, it could likewise be left out of consideration, for in the mechanical model it merely signified process of manufacture. Whether the automaton be of flesh and bone, or of wood and steel, it mattered little, provided it could perform all the duties required of it like an intelligent being. To do so, it had to have an element corresponding to the mind, which would effect the control of all its movements and operations, and cause it to act, in any unforeseen case that might present itself, with knowledge, reason, judgment, and experience. But this element I could easily embody in it by conveying to it my own intelligence, my own understanding. So this invention was evolved, and so a new art came into existence, for which the name "teleautomatics" has been suggested, which means the art of controlling movements and operations of distant automatons."*

In one of his reflections Tesla also says ([4], pp.146):

(d)* *".....to construct a machine which would work as if it were part of a human being, not only a mechanical assembly consisted of handles, screws, wheels, clutches, and nothing more, but a machine embodying a higher principle which would allow performing their duties as if it possessed intelligence, experience, logic, reasoning, soul! This conclusion is a result of my reflections and observations I pursued during my whole life."*

Recollecting the same period later in an "*Electrical Experimenter"* article, he relates ([2], pp.32):

(e)* *"The idea of constructing an automaton, to bear out my theory, presented itself to me early but I did not begin active work until 1893, when I started my wireless investigations. During the succeeding two or three years a number of automatic mechanisms, to be actuated from a distance, were constructed by me and exhibited to visitors in my laboratory. In 1896, however, I designed a complete machine capable of a multitude of operations, but the consummation of my labors was delayed until 1897...when first shown in the beginning of 1898, it created a sensation such as no other invention of mine has ever produced. In November, 1898, a basic patent on the novel art was granted to me, but only after the Examiner-in-Chief had come to New York and witnessed the performance, for what I claimed seemed unbelievable. I remember that when later I called on an official in Washington, with a view of offering the invention to the Government, he burst out in laughter upon my telling him what I had accomplished...*

Teleautomata will be ultimately produced, capable of acting as if possessed of their own intelligence, and their advent will create a revolution. As early as 1898 I proposed to representatives of a large manufacturing concern the construction and public exhibition of an automobile carriage which, left to itself, would perform a great variety of operations involving something akin to judgment. But my proposal was deemed chimerical at that time and nothing came of it."

In 1898, in Madison Square Garden Tesla demonstrated remote control of a boat model (Fig. 1). To control his boat Tesla used the coded pulses of electromagnetic waves (radio control). On demand of the onlookers he commanded the ship to turn left, right, to stop, etc. This boat was a forerunner of all remotely controlled devices and systems. Let us also note that in 1899 in Chicago Tesla showed an improved system of his remotely controlled boat capable also of diving.

The government and especially the military, the most logical customer for Tesla's invention, was simply not advanced enough in its thinking to appreciate the value of this device. As Andrew Carnegie said "Pioneering does not pay." Forty years later, during World War II, radio controlled tanks were developed and deployed by the Germans. It is controlled by radio signals, but they were introduced too late to make a decisive impact on the outcome of the war.

It is known that Tesla also worked on an automotive vehicle that would have ability of quasi-intelligent behavior in surmounting obstacles. "The dexterity of the teleautomatic, conceived first by Nikola Tesla, was undoubtedly one of the most brilliant presents to the world. Tesla went further. He could now make a machine which can think, that is act based on the previously acquired experience. For the sake of illustration, let us imagine a man less car which moves and comes on to a wall blocking the road. Using its appropriate sensors,

the car would not destroy itself by hitting the wall but will slow down and continue left or right. This can be called an intelligent mechanism. Tesla developed a dozen such teleautomatons, many of them being extremely complicated and ingeniously conceived". [5].

About his further investigations in this area Tesla says ([2], pp.32):

(f)* *"The automations so far constructed had borrowed minds, so to speak, as each merely formed part of the distant operator who conveyed to it his intelligent orders; but this art is only in the beginning. I purpose to show that, however impossible it may now seem, an automaton may be contrived which will have its own mind, and by this I mean that it will be able, independent of an operator, left entirely to itself, to perform, in response to external influence affecting its sensitive organs, a great variety of acts and operations as if it had intelligences, I will be able to follow a course laid out or to obey orders given for in advance; it will be capable of distinguishing between what it ought and what it ought not to do, and making experiences or, otherwise stated, of recording impressions which will definitively affect its subsequent actions. In fact, I have already conceived such a plan."*

In all that was presented above we can recognize the elements of control. Sensors are clearly included, own intelligence, tracking of the planned trajectory, execution of the commands given in advance. We should especially pay attention to the expression: "*recording impressions which will definitively affect its subsequent actions* ", which is one of the first descriptions of control loop in general.

In this sense, in his patent application Tesla wrote [6]:

(g)* *"Vessels or vehicles of any suitable kind may be used, as life, dispatch, or pilot boats or the like, or for carrying letters, packages, provisions, instruments, objects, or materials of any description, for establishing communication with inaccessible regions and exploring the conditions existing in the same, for killing or capturing whales or other animals of the sea, and for many other scientific, engineering, or commercial purposes; but the greatest value of my invention will result from its effect upon warfare and armaments, for by reason of its certain and unlimited destructiveness it will tend to bring about and maintain permanent peace among nations."*

Hasn't this already been realized? Aren't we witnessing robotized automated systems that serve people exactly the way Tesla described it? Automated systems have found their application in the armed forces, as Tesla announced it.

In one of his recollections Tesla professed ([4], pp.140):

(h)* *"A multitude of jobs that are presently still performed by human hands will be performed by automaton's hands. At this very moment scientists in the laboratories of American universities endeavor to create something what can be*

described as a thinking machine. Such development I have already predicted. In fact, I have constructed robots. Today, robots are an undeniable fact, but their principles are yet to be explored. In the twenty-first century robots will have the role that slaves had in the ancient civilizations."

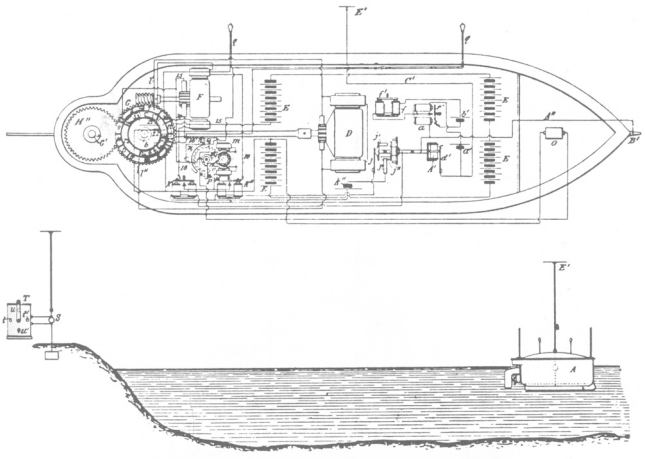

Fig. 1 – *Schematic illustration of Tesla's system of remotely guided boat shown in Madison Square Garden in 1898.*

Therefore we can say with confidence that Tesla regarded the whole area of mechanical systems much wider, not limiting himself only to remote control (as he demonstrated it to the crowd of people his remotely-guided boat in Madison Square Garden in 1898 (Fig. 1)), but he considered also the systems endowed by their own intelligence. About all these things he wrote ([2], pp. 35):

(i)* *"I treated the whole field broadly not limiting myself to mechanics, controlled from a distance but to machines possessed of their own intelligence. Since that time I had advanced greatly in the evolution of the invention and think that the time is not distant when I shall show an automaton which left to itself, will act as though possessed of reason and without any willful control from the outside. Whatever be the practical possibilities of such an achievement it will mark the beginning of a new epoch in mechanics."*

If we pay attention to the way how Tesla used to describe his ideas and inventions, we will recognize segments in which dominate the expressions like "element analogous to human mind", "own intelligence" (of automaton), "own understanding" (of automaton), "independent execution of operations", "possessing something like our reasoning", etc. All these expressions show that Tesla was occupied by control. He speaks about sensors and senses, as well as about reactions to the external stimuli. It can be undoubtedly concluded that Tesla analyzed the problem of control and correction of errors in the course of control.

Therefore, Tesla was aware of the feedback loop as a prerequisite for the detection and correction of errors in the system control.

In Tesla we see the full flowering of the Industrial Revolution, the machine dominates human thinking to the extent that it becomes, in Tesla's philosophy of automata, the model for human functioning, rather than the reverse. The age of robotics has been born [2].

Tesla's hardware seems perhaps less impressive today. However, his sweeping vision of the future is not. In many ways it anticipates Norbert Wiener's Cybernetics [7] which linked biological and mechanical systems in greater detail. Tesla was also the first to see a direct analogy between machines and man in their mechanics, senses, and controls. In this he is first to think of robots, not as dedicated devices, but as complex integrated systems. This is an insight that has been wasted on many modern researchers. As with Leonardo da Vinci, perhaps the future will bring forth some yet unknown work that will further establish Tesla's role as a pioneer of robotics [2].

3 History of Feedback Loop and its Development

In the above survey we tried to prove the relation between Tesla's broad activities and fundamental principles of at the time still officially unrecognized scientific discipline - Robotics, which was just acquiring its basic contours, exemplified in preserving desired performance in a wide range of control of technical systems.

The problem that was considered at that time is related to the phenomenon of feedback, that is to the priority in formulating this notion. To this is also related the question of whether Tesla spoke and wrote of feedback, that is whether he was aware that his discussion was clearing the path to concrete solving feedback loop systems, and whether the remotely guided boat shown in Madison Square Garden in 1898 was only a halfway to automatic control. We know that Tesla reflected about biodynamic, biomechanics, automatics and robotics. A proof of this are his words in citation (a), from which is evident that he analyzed the structure and sought the analogy between living beings and mechanical systems. Moreover, Tesla intended to construct such a system, which he exactly announced in one of his interviews (d). Hence, it is obvious that Tesla predicted the introduction of control of automated systems. We should especially emphasize his statement (b) in which he, as a great visionary, heralded the era of humanoid robotics, that is biped locomotion systems whose structure and mechanical characteristics would remind of humans. In addition to being deeply aware of the need to continue the way to automatic control (f) Tesla unambiguously stated that he participated in the development of robotics (h).

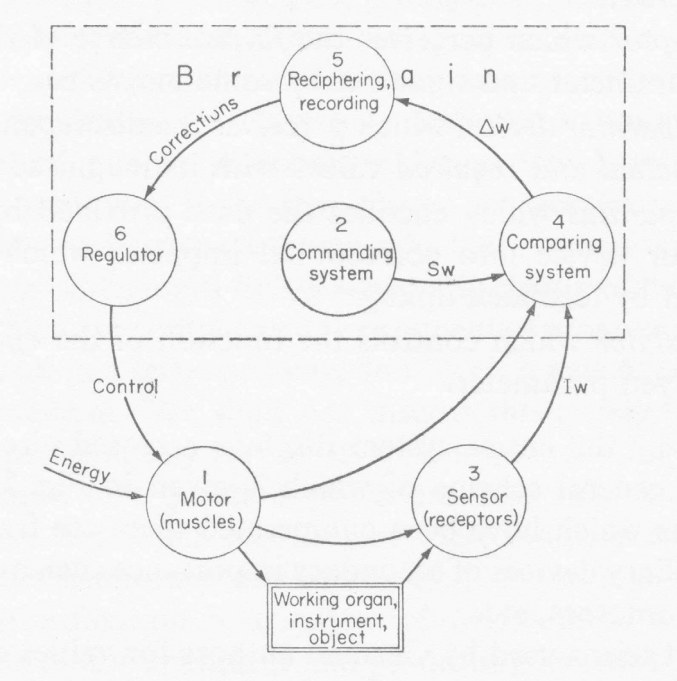

Fig. 2 – *First control scheme in which is clearly shown feedback loop. (according to N. A Bernstein)*

1. *effector (motor) activity, which is to be regulated along the given parameter;*
2. *a programming device which conveys to the system in one way or another the required value of the parameter which is to be regulated;*
3. *a receptor which perceives the factual course of the value of the parameter and signals it by some means to;*
4. *a discriminator which gives the value and the sign of the difference between the actual and desired parameter value;*
5. *a coder which converts the discriminator data into correcting signals that are transmitted to the regulator by means of the feedback loop;*
6. *a regulator which controls the effector operation.*

Concerning the question whether Tesla was a forerunner of robotics we feel obliged to give a brief account of the history of feedback by presenting the results that could more realistically, that is more precisely, give the notion about how and when theoretical bases of automated control have been laid down. This will be given in a most concise form.

One of the scientists that are to be credited with this is certainly Nicholas Bernstein (1894-1966) a great Russian physiologist who started a special branch of Physiological Science – the physiology of activity. He formulated the basic rules of the self-regulating movements of the man.

How to control an artificial locomotion activity, especially humanoid locomotion, it has always been a challenging problem. Bernstein [8] was the first to describe some global feedback and overall control philosophy of such systems. In 1926 Bernstein published his well-known work on general biomechanics [8], and in 1935 he formulated some basic principles of self-regulatory systems and the role of feedback in the regulation of man's voluntary movement [9].

Twelve years later, he completed his basic book *The Construction of Movements* [11], which was published in Russian. Here he formulated the basic rules of self-regulating movements of the man. The description of the basic rules of the self-regulating systems underlying the movement of man, formulated in this book, was a result of the sophisticated physiological and mathematical work of Bernstein, the leading authority in human physiology.

In the foreword to the book The Co-ordination and Regulation of Movements [10], A.R. Luria, wrote: *"...twelve years before the famous publication of Norbert Wiener [7], he formulated some basic principles of self-regulatory systems and the role of feedback in the regulation of man's voluntary movement."* In the same book [10], Bernstein writes: *"In the present analysis we shall have to touch upon many points which have already been thoroughly analyzed in their time [9, 11]; in order to avoid irrelevant repetition I shall dwell on them as briefly as possible in the present report, merely pointing out logical lines of analysis, leaving the reader interested in a more detailed exposition to turn to the works referred to. It will here be best to attempt to complete and extend the questions we have touched upon, which mainly concern the basic principal mechanisms of co-ordination and control, touching in the process upon errors which have now become apparent."*

Finally, it should be pointed out that we were especially fortunate that such an extraordinary mind such as was Nicholas Bernstein, great thinker and scientist of a wide, almost unbelievable erudition busied himself, so extensively and successfully, by the fundamental problems of biodynamic of locomotors act and its regulation, and, using his outstanding ability, performed the synthesis of the most complex mechanisms of human locomotion and control, whose resolving changed the world in the fifties of the twentieth century.

Therefore, Bernstein formulated fundamental principles of control systems and the role of feedback in control of human motion. In Fig. 2 is shown his original control scheme given in [9]. In his book [11], he described the basic principles of self-regulating systems with a special emphasis on human motion.

Let us also mention the outstanding authority of the twentieth century in the domain of automatic control. This is, of course, Norbert Wiener, who in his capital work [7] presented the fundamentals of automatic control and mathematical basis of feedback systems. This capital work contains fundamental principles of modern computer systems, both in the domain of programming and control and in the domain of contemporary information technologies and systems.

4 Instead of Conclusion

Taking into account all the above relevant and undeniable facts, it can unambiguously stated that Nikola Tesla was undoubtedly a true forerunner of robotics. His contribution to theoretical thought and scientific practice in the field of robotics is unavoidable. Thanks to Tesla's work on remote control of automated systems and his (at the time) vanguard visions, special attention has been paid to solving complex problems of control and feedback application. His visions and scientific achievements have stimulated other scientists to think about the problem of automatic control, more precisely, of automatic preservation of desired performance of complex mechanical systems.

The proposed concept of a new method, or its elements, should be decisive in determining the authorship priority. With this in mind, this article of a delicate nature, tackled also some additional elements that may help in the case of this very careful judgment.

Therefore, the fact to be emphasized is that Tesla very often thought and with a great passion spoke of the need for automatic control of robots, and that he, in fact, worked on them. However, we should not forget that it was about fifty years before the official launching of feedback in 1948 [7], and thirty years before Bernstein's book [9] (1935), then unknown to the rest of the world because of the information blockade and inaccessibility of research information at the time.

The conclusions we arrived at in this work may be of a wider significance. Namely, in seeking the answer to the question who is to be credited with the origination of feedback and automatic control a more correct sequence of the important events was presented. However, this does not affect the essence of the mentioned discoveries, as we only mention what and when happened intending no to underestimate anybody's priority in this important matter such as the notion and role of feedback and automatic control theory. It should also be pointed out that Nicholas Bernstein was undoubtedly the founder and promoter of the special branch of physiological science - The Physiology of Activity.

Using the mathematical analysis of human locomotion, Bernstein formulated general laws of organization of human movements. He has illuminated the main problems of regulation of human motor acts. Before him, the science of

human movements and theories of motor co-ordination was merely an obscure branch of human physiology. Bernstein formulated the basic rules of self-regulating movements of the man. The description of the basic rules of the self-regulating systems underlying the movement of man was a result of the sophisticated physiological and mathematical work of Professor Bernstein, the leading authority in this part of human physiology.

These fundamental and pioneering contributions of Bernstein, just a few out of a rich treasure, though presented in a most succinct form, show all the profundity and scientific intuition in setting and solving the problems of extreme complexity, in which for the first time and in a most natural way intertwined biomechanics of locomotor act, mathematics and control theory.

Nicholas Bernstein, great thinker and scientist of a wide, almost unbelievable erudition busied himself, so extensively and successfully, by the fundamental problems of biodynamics of locomotor act and its regulation, and, using his outstanding ability, performed the synthesis of the most complex mechanisms of human locomotion and control, whose resolving changed the world in the fifties of the twentieth century. Bernstein has achievements of highest scientific significance that has been in a direct function of identifying and proving the priority of his pioneering contributions in the domain of feedback, i.e. control and principles of cybernetics.

Once more we shall invoke the statement (h) in which Tesla predicted the future development of robotics, of which we all can give a fair judgment. As is known, first realizations of robots came about several years after Tesla's death (1943). Thus the first electronic autonomous robot was constructed by Grey Walter from University of Bristol (UK) in 1948 (Fig. 3). In Fig. 4 is shown the first industrial robot patented and constructed by George G. Devol in 1954. An improved version of this robot was used first time in a General Motors factory in 1961, under the guidance of Joseph Engelberger, who is considered to be father of industrial robotics. Nowadays, robots literally work instead of us, just the way Tesla envisaged it.

In the light of what has been presented in this article, Tesla's contribution to the introduction of automatic control becomes more significant and more obvious. As a scientist, visionary and constructor of the end of 19th and beginwning of 20th century, Tesla laid the fundamental postulates of automatic control and indicated the basic functions of the feedback. By his visions and perceived problems, as well as by his realized patents and solutions, Tesla has clearly paved the way for the present-day modern robotic systems.

Fig. 3 – *Robot constructed by Walter Grey, University of Bristol.*

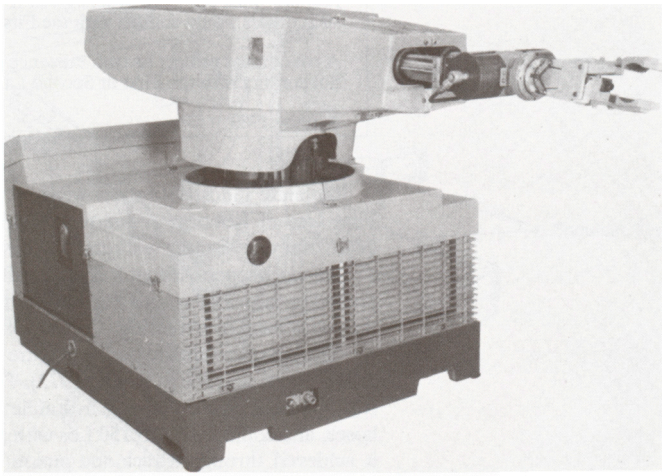

Fig. 4 – *First industrial robot "Unimate", constructed by George Devol in 1954. Installed in a General Motors factory in 1961 after modifications made by Joseph Engel-berger, who is considered to be father of industrial robotics.*

Note: A detailed analysis of Tesla's few texts addressing object (mechanism) control should have shed a clearer light on the scientific and research essence of his work from that period. In other words, it was already then that Tesla realized that his scientific and professional efforts in this field were his engineering preoccupation, a number of decades before the first industrial robots. In this way Tesla anticipated the epoch of robotics, or the coming of "a new world" which he felt and understood, before other people, as "a must" of further mankind's engineering and technology development. We have to bow before his visionary stimulations to the coming novelties such as robotics and robots. This is why

Tesla is undoubtedly the forerunner of robotics. He was the first to deal with it and we thank him for that as well as for other areas of his creative work.

5 Acknowledgement

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