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Historical Female Influencers in Automatic Control

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Abstract: Over the last century, many women have contributed to the field of control engineering. Nevertheless, women are generally in the minority. This article highlights the contribution of women since the inception of control engineering to highlight good exemples to coming generations. A repository of portraits of women in control engineering is currently being curated and made available through the university of Lund website. The main purpose is to provide role models for future generations of control engineers. This article describes the need for role models as a means to change the situation and attract more women to control engineering in the future. Two portraits in the repository – those of Irmgard Flügge-Lotz and Nina Thornhill – are presented here. Ideas on how to use this resource are provided.

Keywords: Control engineering education, diversity and inclusion, gender, equality

1. INTRODUCTION

Diversity is important, it widens viewpoints and takes different ideas and perspectives into account. This can translate into creating richer solutions and obtaining better results. Many studies have shown that a diverse workforce is more productive and creative (Saxena, 2014). Diversity is also important in the area of engineering. A more diverse perception of what an engineer is and what attributes an engineer should have could result in better products, services and a larger workforce. Gender diversity is insufficiently addressed in engineering in general. Currently there are not enough engineers and by not fully including women you will miss out on a big portion of the potential workforce. Studies estimate that at the current rate it will take 108 years to achieve gender equality (Sharma et al., 2021).

Despite the limited number of women, there are and were many who have contributed extensively to the development of control engineering. This article presents material collected on women who have been influential in the area of control engineering and who have dedicated their career to research and teaching in this field. It focuses on women born before 1960 and hence have the majority of their working career behind them. These women are refered to as historical female influencers in control engineering. They can all serve as role models for the younger generation, enhancing and extending the often stereotypic perception of who can be a control engineer.

The results from a project called "Historical Female Influencers in Automatic Control" are presented here. The project investigated early female control engineers, and interviews were conducted with a selected number of those pioneers. Thereafter, work has been done to create portraits of these women. In addition to this, a webpage has been created providing information and presentation material that can be downloaded.

This article first discusses the current status of diversity in control engineering in Section 2 and thereafter it introduces 17 women who have been influential in control engineering in the past. The introduction is done in the form of a timeline in Section 3. Two of the portraits that were generated are presented in Section 4. A description of how the result of the project, i.e. the webpage, portraits and presentations, can be used for a number of purposes is given in Section 5.

2. ROLE MODELS

In Control engineering, there generally is a lack of gender diversity. Mostly, there are few women in undergraduate courses and even less in higher education and in the work place. For women in control engineering it is a vicious cycle of not seeing any female control engineers and thus not considering a position of a control engineer in the future. This gender inbalance is also recognized by organisations such as IFAC and IEEE.

One way of breaking the vicious cycle is to make sure that the few early female control engineers are made known to the younger generation. These females can act as role models for younger girls and women. Role models are a powerful source of social learning which can affect the way people view themselves and the world around them. Ultimately, role models can affect people's decisions about how to conduct their lives including e.g. their careers. Recent research has shown that for girls, female role models played an important part in increased career participation and attainment, but crucially, they were able to gain this influence from a variety of female role models — not always necessarily from their own mothers. (Hagh, 2021).

A role model is a person who serves as an example by influencing others, and inspiring others to imitate his or her behaviour. When we are young and grow up, the role model is usually an elder person, someone who we admire. Often it is a parent, a teacher, a sibling or an elder friend that we look up to and, intentionally or unintentionally, get inspiration from. As we grow older, and start to shape our working life, it becomes important to have professional role models, someone that we can identify ourselves with, someone who demonstrates, in a good way, how our working life could be. Having them around pushes us to make the most out of our working life. It is interesting to look at the presence of role models in the control community. The elder professionals in this field, influence the younger, and thereby shape the younger generation. There are many occasions where younger, potential future control professionals, could be influenced by senior professionals. One occasion is in the class room when examples of pioneers in the field are highlighted. One other example is in the everyday working environment e.g. laboratories or offices, where histories and anecdotes from the past are shared. Yet another example, are the award winners in the field, who just by getting the price raises their influence in the field.

Statistics from the Department of Automatic Control at Lund University, Sweden, show that only eleven out of the 128 PhD theses, throughout its 60 years of history, are written by women. In the same department, only 14% of the PhD-students, and 9% of the professors are of female gender. These numbers are very low. Most probably the statistics from control departments in other corners of the world, are very similar. Could it be that female role models are missing?

It is noted that early pioneers highlighted in basic control courses are often, if not always, men. Examples that come to mind are Harry Nyquist (b. 1889), Hendrik Wade Bode (b. 1905), Nathaniel B. Nichols (b. 1914) and Rudolf E. Kalman (b. 1930). In addition, winners of control engineering awards are to a very large degree men. e.g. Richard E Bellman Award was given to a man 40 years in a row, with the only exception in 2019, when it was given to a woman. The IFAC Fellow Award is given to persons who have made outstanding and extraordinary contributions in the field of interest of IFAC, in the role as an engineer/scientist, technical leader, or educator. The first IFAC Fellows were elected at the IFAC World Congress in Prague in July 2005 and until the period of 2023, out of 231 Fellows, only 13 were women.

3. TIMELINE OF WOMEN IN CONTROL ENGINEERING

There are not many women in the history of control engineering. The purpose of this work is to highlight the achievements and lives of the women that contributed to the development of control theory and applications. In a first step, these engineers need to be identified. The authors applied different strategies. First, the recipients of significant awards were collated. Furthermore, senior colleagues were approached and asked to recollect their interactions with women they encountered over the years. An additional resources is the article by McClamroch and Pasik-Duncan, published 20 years earlier in 2002 that highlights six women, who are included in the overall list. The non profit bodies of IFAC and the IEEE CSS were approached.

The current results of the ongoing investigation are presented in a timeline in Figure 1. A key criteria put here is that the women should be at retirement age, which in most of Europe is 65 years of age and that the women should have dedicated their career to control engineering. Possibly one exception included here is the Russian/Swedish mathematician Sofja Kovalevskaja. Sofja Kovalevskaja did ground breaking work on partial differential equations, a foundation for control systems. The absence of women born between 1903 and 1928 can be explained with the impact of the first and second world war that made the career for women in technical areas even more unlikely. Table 1 lists the geographical location (country and, when known, city) as well as the research areas.

The authors are looking forward to receiving information on women they might have missed. The list will be updated in the repository on an ongoing basis and maintained by the control engineering researchers at Lund University.

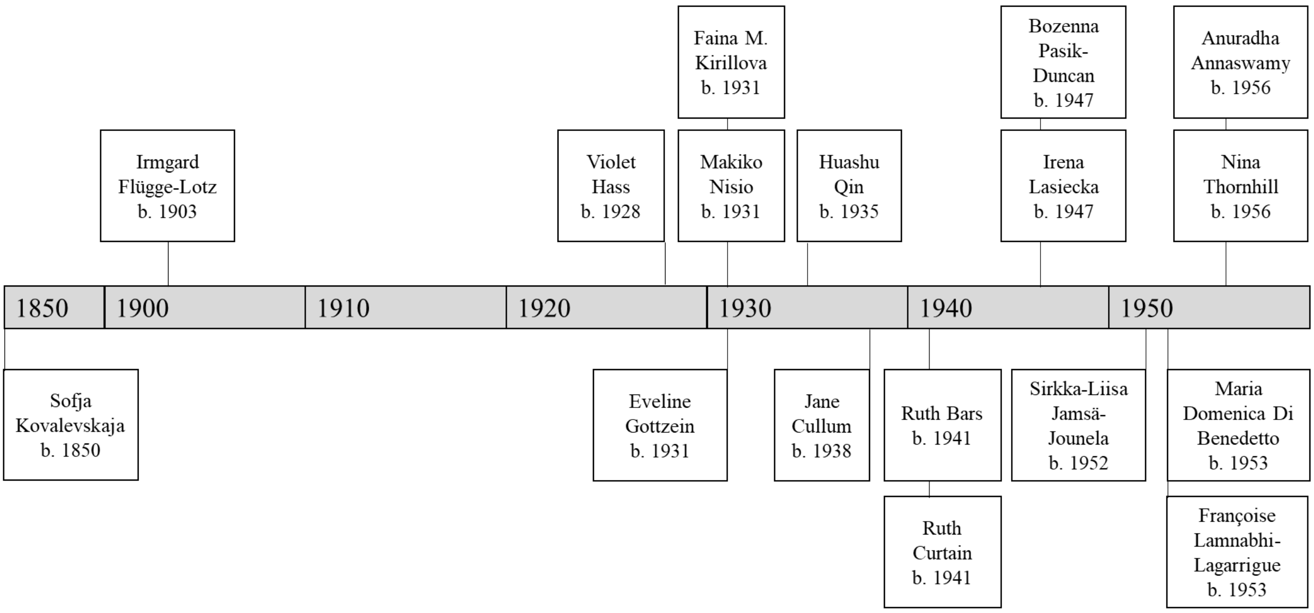

Figure 1. Timeline of female historical influencers in control engineering.

Table 1. List of female historical influencers in control engineering

Name	Year of birth	Place of birth	Main affiliation	Research area
Sofja Kovalevskaja	1850	Moscow, Russia	Stockholm University, Sweden	Partial differential equations
Irmgard Flügge-Lotz	1903	Hameln, Germany	Stanford University, US	Discontinuous control
Violet Hass	1928	New York City, US	Purdue University, US	Singular optimal control
Faina M. Kirillova	1931	Zuevka, Russia	Belarusian State University	Optimal control
Makiko Nisio	1931	Japan	Kyoto University, Japan	Stochastic control
Eveline Gottzein	1931	Leipzig, Germany	University of Stuttgart, Germany	Aerospace control
Huashu Qin	ca. 1935	China	Chinese Academy of Sciences, China	Systems and control
Jane Cullum	1938	Virginia, US	IBM, New York, US	Large systems simulation
Ruth Bars	1941	Budapest, Hungary	University of Budapest, Hungary	Predictive control
Ruth Curtain	1941	Melbourne, Australia	University of Groningen, The Netherlands	Linear systems theory
Bozenna Pasik-Duncan	1947	Radom, Poland	University of Kansas, US	Stochastic control
Irena Lasiecka	1947	Warsaw, Poland	University of Memphis	Mathematical control theory
Sirkka-Liisa Jamsä-Jounela	1952	Haapajärvi, Finland	Aalto University, Finland	Process control
Maria Domenica Di Benedetto	1953	Rome, Italy	University of L'Aquila, Italy	Hybrid and embedded systems
Françoise Lamnabhi-Lagarrigue	1953	Toulouse, France	CNRS, France	Power systems control
Nina Thornhill	1956	UK	Imperial College London, UK	Process control
Anuradha Annaswamy	1956	India	MIT, US	Adaptive control theory and smart grids

4. PORTRAITS

Beyond the listing these engineers, more material was collected and the material was developed into portraits. Currently, there are only two portraits included in the repository. In this section we are presenting the portraits of two control engineers – Irmgard Flügge-Lotz and Nina Thornhill. These two women were chosen because they are very different. They represent two different fields of control, and also represent two generations. The intention is to collate more portraits. More portraits are currently compiled and will be published in the future.

4.1 Irmgard Flügge-Lotz (1903-1974)

Irmgard Flügge-Lotz was a German mathematician and pioneer in aviation theory and the theory of discontinuous automatic control. She is particularly known for her advancements in the spanwise lift distribution of an airplane wing, known as the Lotz method, and the development of the on-off control.

<u>The Lotz method:</u> Early on in her career, when working at the Aerodynamische Versuchsanstalt (AVA) in Göttingen, which was one of the most prominent aeronautical research institutions in Europe at the time, Irmgard Flügge-Lotz developed a method for calculating the lift of a three-dimensional wing. Before she arrived at AVA, Ludwig Prandtl, a leading German aerodynamicist, had been unsuccessfully working on solving a differential equation for his lifting-line theory for the spanwise lift distribution of an airplane wing. Irmgard Flügge-Lotz was able to solve the equation and additionally developed a relatively simple method for practical use. The method became known as the Lotz method and became a standard technique used internationally.

<u>On-off control:</u> Later in her career, Irmgard Flügge-Lotz also developed the theory of discontinuous or on-off control

systems, the simplest form of feedback control. An on-off controller drives the manipulated variable from fully closed to fully open depending on the position of the controlled variable relative to the setpoint. A typical example of on-off control is temperature control in a domestic heating system. When the temperature is below the thermostat setpoint, the heating system is switched on, and when the temperature is above the setpoint, the heating switches off. There are many examples of discontinuous control systems in our house appliances, for example, fridges and freezers, ovens and water heaters. They also occur in some non-critical industrial appliances, where the error between the setpoint and plant output can vary with a relatively large amount, such as furnaces.

Figure 2. Irmgard Flügge-Lotz.

"*I wanted a life which would never be boring. That meant a life in which always new things would occur. I wanted a career in which I would always be happy, even if I were to remain unmarried.*" – Irmgard Flügge-Lotz

Standford's first female professor of engineering: In 1960, Irmgard Flügge-Lotz was appointed professor at Stanford University, making her the first female engineering professor at Stanford. She received many honours and awards, including the Achievement Award by the Society of Women Engineers (1970) and an honorary doctorate of science by the University of Maryland (1973). She was also chosen by the American Institute of Aeronautics and Astronautics to give the prestigious annual Karman lecture in 1971. In the citation from her honorary doctorate, evaluators wrote: "Professor Flügge-Lotz has acted in a central role in the development of the aircraft industry in the Western world. Her contributions have spanned a lifetime during which she demonstrated, in a field dominated by men, the value and quality of a woman's intuitive approach in searching for and discovering solutions to complex engineering problems. Her work manifests unusual personal dedication and native intelligence."

Early interest in engineering: Irmgard Flügge-Lotz was born in Hamelin, Germany in 1903. Already at an early age, she showed a great interest in engineering and construction. For many generations, her mother's family had been involved in construction, and Irmgard Flügge-Lotz often visited construction sites with her uncle and attended matinee shows for technical films. After graduating from a girls' gymnasium in Hamburg in 1923, she entered Leibniz University in Hannover. She was encouraged by her mother to pursue technical subjects and chose to study mathematics and engineering. She was often the only woman in her class. In 1927, she received her diploma but remained in Hannover to earn her doctorate in engineering. Her thesis was about the mathematical theory of heat conduction in circular cylinders. During this time, she also held a full-time job as a teaching assistant in practical mathematics and descriptive geometry.

Career progress: Though it was difficult for a female to find a job in engineering, Irmgard Flügge-Lotz received two offers; one from the steel industry and one from the Aerodynamische Versuchsanstalt (AVA) in Göttingen. She chose the latter. It is said she was asked to devote half her time to clerical work, leaving only half for research. However, her career progressed well, and in 1938 she was appointed head of the Department of Theoretical Aerodynamics. In 1938, Irmgard Flügge-Lotz married Wilhelm Flügge, a civil engineer. In the following year they moved to Berlin where Wilhelm Flügge had accepted a position at the Deutsche Versuchsanstalt für Luftfahrt (DVL). The leaders of DVL quickly became aware of the talent possessed by Irmgard Flügge-Lotz, and they offered her a position as a consultant on aerodynamics and flight dynamics. In the spring of 1944, the destruction of Berlin had progressed so far that Irmgard and Wilhelm Flügge-Lotz moved with their departments to Saulgau, a small town in the hills of southern Germany. When Germany surrendered the war, the Flügges found themselves in the French occupation zone. In 1947, they accepted offers to join the newly established Office National d'Études et de Recherches Aéronautiques. They moved, with many of their co-workers, to Paris. Irmgard Flügge-Lotz served as a chief of a research group in aerodynamics and published papers in both automatic control theory and aerodynamics, discussing, for example, the problems arising from the increased speed of aircraft.

The Stanford period: In 1948, the Flügges accepted offers to teach at Stanford University. Despite Irmgard Flügge-Lotz's reputation in research, she had to take the relatively minor lecturer position while her husband became a professor due to the Stanford policy that spouses could not both hold a professional title in the same department. However, Irmgard Flügge-Lotz immediately began accepting PhD students for aerodynamic theory research, and in the spring of 1949, she taught her first course in boundary layer theory. She worked hard, guided the research of a succession of PhD candidates, developed courses, and established a weekly fluid mechanics seminar where faculty and students met to discuss ideas. She published a number of papers, among other things, in numerical methods to solve boundary layer problems in fluid mechanics (which is important to predict and explain the turbulence between a moving liquid and a relatively stable solid), and made extensive advancements in finite difference methods (one of the methods used to solve differential equations that are difficult or impossible to solve analytically) and the use of computers. In 1953, she published the first textbook on discontinuous automatic control. Irmgard Flügge-Lotz was carrying on the duties of a full-time professor without official recognition. In 1960, Stanford finally appointed her as a full professor in engineering mechanics, aeronautics, and astronautics, and she became their first female professor of engineering.

Over time, her research efforts went increasingly into control theory. In 1968, she published her second book called "Discontinuous and optimal control". That same year, she retired but continued to research satellite control systems, heat transfer, and high-speed vehicle drag. She published over fifty technical papers.

4.2 Nina F. Thornhill

Nina Thornhill is a British physicist and control engineer. She is mainly known for her innovative approaches and tools for process monitoring and the detection and diagnosis of persistent faults in large-scale industrial systems, such as chemical plants. Her practical and effective methods have reduced the use of raw materials and energy, increasing the efficiency of the production facilities and making them significantly more sustainable.

<u>A predecessor of big data and Industry 4.0:</u> Long before the current era of big data and artificial intelligence, Nina Thornhill researched data analytics. In 1984, the same year as the 3.5 floppy disk was introduced, she was doing data-driven monitoring of fermentation processes. Computers were introduced into the process industry in the eighties, and computer-based systems replaced analog instruments. As a result, problems and malfunctions in the plants were suddenly not so easily discovered, and there were issues with poorly tuned controllers and equipment problems. The situation sparked interest in the academic community, and Nina Thornhill was one of the researchers taking on the challenge of improving the situation in the production plants. Some of her early and most significant research involved the development of time-series analysis, control loop performance assessment, valve stiction analysis, and oscillation detection – all focused on optimization for industrial value. Later on, she made significant advances in plant-wide data analysis and was one of the first researchers to combine the chemical, mechanical and electrical subsystems of a plant, resulting in increased automation and efficiency of industrial practices – the beginning of what is now known as Industry 4.0 or Smart Process Manufacturing.

<u>Cooperation with industry key to success:</u> Many of Nina Thornhill's key scientific achievements came about as a result of secondments and sabbaticals at various industrial institutions. For example, during her 23 years at University College of London, Nina Thornhill spent two years with BP Oil and BP Chemicals and six months as an academic visitor at ABB Norway Corporate Research Centre. She also visited ABB Corporate Research Centre in Poland on several occasions. The Royal Academy of Engineering and ABB recognized her excellence in combining academic research and industrial relevance and her interest in collaborative technology transfer projects. Subsequently, they funded her chair of Process Automation at Imperial College London in 2007. In 2010, she became a fellow of the Royal Academy of Engineering. In 2019, Nina Thornhill received the Nordic Process Control Award for her contributions to research and significant contributions as a coordinator of several European Marie Sklodowska-Curie projects, bringing together industrial and academic partners to train early-stage researchers in the field of process automation and control.

<u>Early interest in engineering:</u> Already at an early age, Nina Thornhill was intrigued by technology. At age ten, her father, who was a big influence on her, took her to a nuclear power station he designed. The walk through one of the reactor halls excited her, and the memory remained throughout her childhood. Nina Thornhill decided to become a physicist.

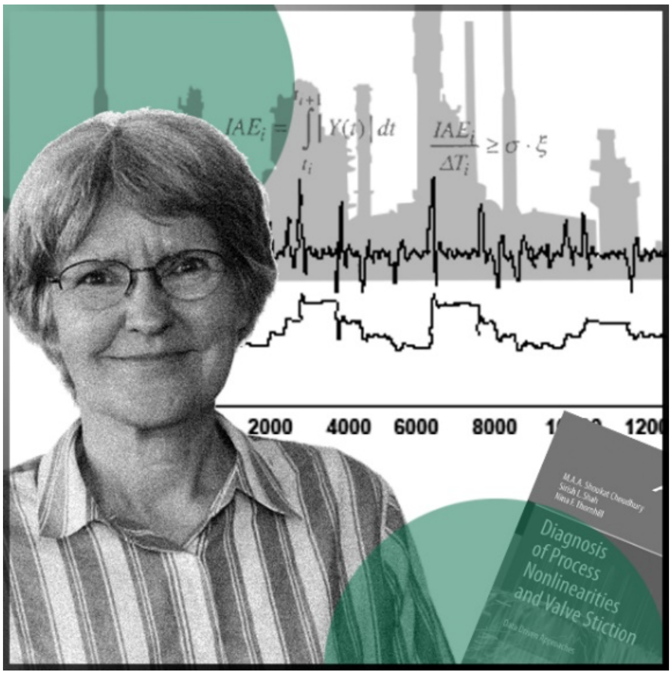

Figure 3. Nina F. Thornhill.

"You can find anything you want in data, but whether it is meaningful requires one to understand the processes behind the analysed systems." – Nina Thornhill

In 1976, Nina Thornhill received her undergraduate degree in physics from Oxford University. She then joined Imperial Chemical Industries (ICI), Britain's largest chemicals and pharmaceuticals manufacturer at the time. Her interest in engineering, automation, control, and data analysis commenced. She was one of the first employees to have an online computer attached to an ICI instrument, which inspired her to continue working in online data and analysis.

<u>Struggled with maths:</u> In 1983, she left ICI to study for a master's degree in control systems at Imperial College London. She has described her second round of studying as quite different from her first. In particular, she had a completely different comprehension of mathematics. "As an undergraduate doing physics, I struggled quite badly with

mathematics, especially if it was abstract. If it was applied to something, I could do it. If it was maths by itself, I could not do it. I had no mental model at all. Then, when I went back to Imperial College, somehow I was suddenly very good at maths. I didn't do any maths for six years. And then suddenly I could do everything. It is extraordinary; it is intuitive in my brain without me knowing. So now I'm quite good at maths." After her master's degree, she went back to the industry to work as a control systems engineer for British Aerospace. A few years later, Nina Thornhill returned to academia, becoming a lecturer at the Department of Electronic and Electrical Engineering at the University College of London. She stayed at the department for 23 years, becoming a professor in 2003. In 2007, she received the ABB/Royal Academy of Engineering Chair of Process Automation at the Department of Chemical Engineering, Imperial College London.

A supportive supervisor who enjoys work: Besides research, Nina Thornhill has always had a great interest in education. At Imperial College London, she set up the master's program in process automation, instrumentation, and control, of which she was the director. She has also served as the director of undergraduate studies at the Department of Chemical Engineering and has devoted her time to several foundations endorsing scholarships to engineering and research students. She has put pride in performing administrative duties and making improvements to facilitate teaching for the academic staff and improve the education of the students. Her colleagues define Nina Thornhill's work approach as one of critical questioning, never forgetting the bigger picture, and always being problem-solving oriented. She herself said: "I never felt that I was struggling to do my job or had doubts if it was the right job for me. On the contrary, I always really enjoyed it. I think I have been extremely fortunate." Furthermore, she has emphasized that she never felt discouraged or bullied for pursuing a career in engineering as a female. Instead, she felt encouraged, in particular by a senior manager at ABB in Norway. He reassured her to do things she was not entirely confident to try, something that Nina Thornhill has since attempted to transmit to her students, encouraging them always to aim as high as they can.

5. HOW TO USE THE MATERIAL

This material highlights historical female control pioneers i.e. early role models. The general thought is that everyone in the field will benefit from a more gender equal field. The field cannot reach its full potential, when a big portion of the contributors are not finding their way into the field. Therefore, the material will be of importance to the field itself. It is also expected that the material will find an additional purpose amongst young, female, and potential PhD candidates, that today may have difficulty finding anyone in their work and study environment to identify with.

The material is available in different formats: as a web resource, as power point slides, as images and as this article. Table 2 lists the different purposes for which the material can be used: for teaching, self-study and self-learning and to raise awareness amongst others. Examples are an introductory lecture to control. Another suggestion is to use for example the portrait of Irmgard Flügge-Lotz right at the beginning of the course when explaining on/off (or bang-bang) controllers for which she developed mathematical theory. Some guidelines which material can primarily be used for which purpose are given in Table 2, and additional guidelines can be found in (Bohnet, 2016). All the material is available via the website of the Dept of Automatic Control at Lund University.

https://www.control.lth.se/external-engagement/visits-and-outreach-activities/historical-female-influencers-in-automatic-control/

Table 2. Use of the different material

	Web	Slides	Image	Article
Teaching	X	X	X	
Learning (self)	X			X
Awareness (others)	X	X	X	

6. CONCLUSIONS

The intention of the repository of inspiring women in the field of control engineering is to be used in education and to attract more women to the field of control. It is necessary to celebrate the women who have contributed to the development of the field, sometimes despite many obstacles. The authors hope that the material will be used in undergraduate teaching, for individual studies and possibly even in diversity workshops to highlight the role that women can and have played. Control engineering is generally not a diverse discipline and the material can be extended to further aspects of diversity beyond gender.

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