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Editorial

Quantitative Feedback Theory. In Memoriam of Isaac Horowitz

The influence of Professor Isaac Horowitz (1920–2005) in the understanding of automatic control theory for more than half a century has been very extensive and world wide. He was the first one who introduced a formal combination of the genuine frequency methodology founded by Hendrik W. Bode [1] with plant ignorance considerations under quantitative analysis [2]. He was a genius in the areas of system sensitivity, feedback constraints, closed-loop performance specifications, nonlinear and multivariable systems, and model uncertainty. He paved the way between the more complex mathematical field and the practical engineering world [3, 4].

Moreover, Isaac belonged to one of the most prominent lineage of scientists in history [5]. Looking at his 'family tree' of PhD advisors (Figure 1), one readily recognizes some of the most important mathematicians and scientists in history. Isaac Horowitz obtained his PhD in 1956 at the Brooklyn Polytechnic Institute where he did his dissertation under the supervision of John Truxal. Truxal had done his PhD dissertation in 1950 under the supervision of Ernst A. Guillemin at MIT. In 1926, Guillemin was in Munich, where he did his research under Arnold Sommerfeld, who was in Königsberg and did his research under C. L. Ferdinand Lindemann in 1891. Lindemann in 1873 was in Nürnberg where he did his research under C. Felix Klein. Klein, who received his PhD in 1868 in Bonn, had two advisors: Rudolf Lipschitz and Julius Plüker. Plücker, who obtained his PhD in 1823 in Marburg, studied under C. L. Gerling who in-turn, in 1812 studied under Carl Friedrich Gauss in Göttingen, who did his PhD dissertation in Helmstedt in 1799. In addition, Lipschitz, who obtained his PhD in 1853 in Berlin, had two PhD advisors, Gustav Dirichlet and Martin Ohm. Dirichlet obtained his PhD in 1827 in Bonn who also had two advisors: Siméon Denis Poisson and Jean-Baptiste Joseph Fourier. Both of these individuals studied under Joseph Lagrange, who studied under Leonhard Euler. Euler, who was in Basel in 1726, studied under Johann Bernoulli, who in 1694 studied under his brother, Jacob Bernoulli. Jacob studied under Gottfried W. Leibniz. Leibniz obtained his PhD in Altdorf in 1666. This lineage of scientists formed Isaac's foundation of knowledge that contributed to him becoming a pioneer in control theory.

Horowitz was a unique individual who not only had a deep knowledge in the control theory area but also in other areas of engineering, in the field of mathematics, and in the experience gained from his diversity of practical engineering work. Isaac's uniqueness led him to the realization that this body of theoretical knowledge (scientific method) must be coupled with 'the body of engineering knowledge' pertaining to the application, when dealing with nonlinear systems and real-world problems. This uniqueness can best be described by the phrase 'bridging the gap.' This 'bridging the gap' can be highlighted by the following

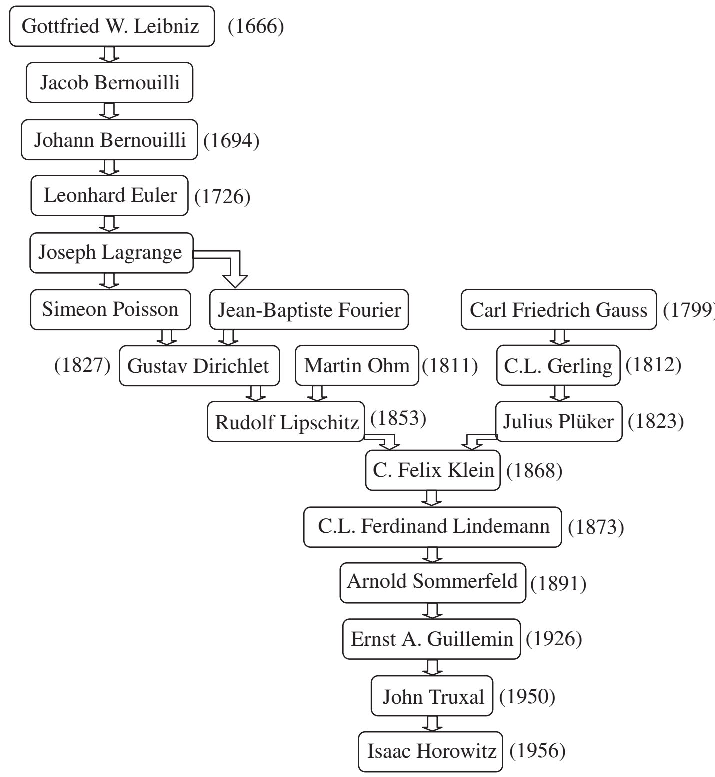

Figure 1. Isaac Horowitz's family tree of PhD advisors (with the year of the dissertation).

anonymous quote:

'In THEORY (scientist)
There is no difference between theory and practice.
In PRACTICE (engineer)
There is a difference between practice and theory.'

Thus, Isaac strongly felt that an engineer must have a firm understanding of the results of the scientific method and of the nature and characteristics of the plant to be controlled in order to achieve a practical and a realistic control system design.

This uniqueness was the basis for his nomination for the American Society of Mechanical Engineers (ASME) Oldenburg Award, which he received in 1991, and is best described by the following testimonials which were submitted for this award:

Prof. Suhada Jayasuriya of Texas A&M, stated that 'Prof. Isaac Horowitz has made a lifetime of contributions to the practice and theory of robust control and has been a significant influence on changing the course of the controls field.'

Prof. Eduard Eitelberg of the University of Kwazulu-Natal, stated the following: 'Isaac Horowitz is an essential singularity in the complex domain of control systems, where no amount of zeros can cancel his impact upon the application of control theory, that is, the

Horowitz's way and his simple message that '*feedback is only necessary when there is uncertainty which must be reduced in some quantifiable manner*.' Isaac Horowitz did all that and very much more on the arithmetic complex plane without any 'help' from computers and without calling it QFT. Any serious student of feedback control theory must eventually study carefully Isaac's first book of 1963 [2].'

Another uniqueness of Isaac's was his ability to inspire others, such as the Editors of this article, and this inspiration can best be described by paraphrasing Professor P. S. V. Nataraj of IIT, Bombay, India as follows:

'My learning of QFT began in 1990 and I was captivated by its simplicity and brilliance. I jumped in at once, and since then have been learning, teaching, and applying this wonderfully practical tool at IIT Bombay. I have just this much to say to the memory of Professor Horowitz: 'Thank you, sir for this wonderful invention.'

In conclusion, Isaac Horowitz's legacy can be readily expanded to include other areas of scientific and engineering endeavours—*bridging the gap* between theory and the real-world problem.

Because of the large number of papers submitted to the journal for the Special Issue honouring Professor Horowitz after his death, the IJRNC Board decided to enlarge this issue, including the following nine contributions.

In the first paper, Eduard Eitelberg and Constantine H. Houpis present a short eulogy of Isaac Horowitz, who they define as a truly dominating figure in control theory, just like an essential singularity, whose impact cannot be cancelled by any number of zeros.

The second paper, written by Murray Kerr, Chen-yang Lan and Suhada Jayasuriya, presents a generalized formulation for multi-input multi-output (MIMO) quantitative feedback theory (QFT) based upon controller design and analysis, and its application to the control of the X-29 aircraft. This paper also applies Horowitz's Singular-G design methodology for the X-29 and redesigns the controller using the exploitation of directions in non-sequential MIMO QFT.

In the third paper, Mario Garcia-Sanz, Ana Huarte and Alex Asenjo introduce a new simple quantitative robust control technique designing applicable one-point feedback controllers for distributed parameter systems (DPS) with uncertainty. This paper considers the spatial distribution of the relevant points where the inputs and the outputs of the control system are applied and presents a new set of quadratic inequalities to define the QFT bounds. The method deals with uncertainty in both the model and the spatial distribution of the inputs and the outputs.

The fourth paper, written by Per-Olof Gutman, Mattias Nordin and Bnayahu Cohen, proposes recursive extensions to the standard equidistant Grid method to compute templates (value sets) and Horowitz-Sidi bounds (QFT bounds, or boundaries). The main advantage of the proposed recursive grid method is the fact that it is possible to determine the required resolutions *a priori*.

In the fifth paper, Edward Boje examines the feedback design possibilities for uncertain plants where the underlying parameterization is described by a probabilistic rather than a deterministic set membership.

The sixth paper, written by Alfonso Banos, revises the original nonlinear QFT techniques of Prof. Horowitz, trying to contribute to the systematization of the field and reviewing some of the contributions made over the last three decades. The material is presented in a tutorial style, simplifying the exposition to mathematics, and using very simple examples that are expected to reveal the internal mechanisms of nonlinear QFT, basically based on a clever application of Schauder's principle.

Based on the original Horowitz's ideas about dynamic analysis of parallel plant structures on the frequency domain (1963), Eduard Eitelberg introduces in the seventh paper a new approach to understand the macroeconomic interaction between trade and production feedback loops. This paper studies the problem as a multi-loop system with load sharing between the parallel plants and reaches significant results about macroeconomic cycles and their control.

In the eighth paper, N. Niksefat, N. Sepehri and Q. Wu present design and experimental evaluation of a robust contact task controller for an electro-hydraulic actuator that operates under significant system uncertainties and nonlinearities. The scheme is essentially the combination of two distinct control laws designed for position regulation in free space and force regulation during sustained contact. Both controllers are designed using nonlinear QFT and switching laws based on an extended version of Lyapunov's second method under the condition of existence and uniqueness of Filippov's solution. Experiments, performed on a typical industrial hydraulic actuator, show good performance in both transient and steady-state periods.

The ninth and last paper, written by Paluri S. V. Nataraj and Nandkishor Kubal, proposes an efficient method for automatic loop shaping in QFT. The proposed technique uses a combination of interval global optimization and nonlinear local optimization methods with constraint propagation ideas. The new method is demonstrated on an example where it automatically synthesizes a QFT controller of a given structure in a very short time.

We hope that this Special Issue will contribute to extending the knowledge and interest about the extraordinary and prolific work of Prof. Isaac Horowitz, and will inspire new research and developments on this central field of control theory and engineering. As Guest Editors, we would like to thank the authors for their contribution to this Special Issue, and all the reviewers and the editorial staff of the IJRNC for their support.

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MARIO GARCIA-SANZ AND CONSTANTINE H. HOUPIS

Public University of Navarra, Spain

Air Force Institute of Technology, U.S.A.