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Zhihong Qian, Lei Cao, Weilian Su,
Tingkai Wang, and Huamin Yang (Eds.)

# Recent Advances in Computer Science and Information Engineering

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# Preface

On behalf of the organizing committee of the 2nd World Congress on Computer Science and Information Engineering (CSIE 2011), we would like to express our highest appreciation to all authors from all over the world.

CSIE 2011 is an international scientific Congress for distinguished scholars engaged in scientific, engineering and technological research, dedicated to build a platform for exploring and discussing the future of Computer Science and Information Engineering with existing and potential application scenarios. The professional interaction, afforded by this congress, will permit individuals with common interests the opportunity to share ideas and strategies. We believe that the congress will also develop a spirit of cooperation that leads to new friendship for addressing a wide variety of ongoing problems in this vibrant area of technology and fostering more collaboration in China and beyond.

The congress received 2483 full paper and abstract submissions from all over the world. Through a rigorous peer review process, all submissions were refereed based on their quality of content, level of innovation, significance, originality and legibility. We would like to apologize to those authors whose papers were declined due to the limited acceptance capacity. We are extremely grateful to each author, no matter whether his/her paper has been accepted or not.

We greatly appreciate all those who have contributed to the congress and express our grateful thanks to all supporters for their time and assistance. Thanks go to IEEE Harbin Section, Changchun University of Science and Technology, Jilin University, TPC members of the congress, for their support and hard work, without which we could not perform so efficiently and successfully. Thanks go to all the reviewers, speakers and participants for CSIE 2011.

Our day to day work in the CSIE 2011 field must always be sustained by a positive outlook and a real sense of joy from our awareness of the valuable work we do and the great contribution we make.

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# Keynote Speakers

## Ivan Stojmenovic

**Title: Contribution of applied algorithms to applied computing**

**Abstract:** There are many attempts to bring together computer scientists, applied mathematician and engineers to discuss advanced computing for scientific, engineering, and practical problems. This talk is about the role and contribution of applied algorithms within applied computing. It will discuss some specific areas where design and analysis of algorithms is believed to be the key ingredient in solving problems, which are often large and complex and cope with tight timing schedules. The talk is based on recent Handbook of Applied Algorithms (Wiley, March 2008), co-edited by the speaker. The featured application areas for algorithms and discrete mathematics include computational biology, computational chemistry, wireless networks, Internet data streams, computer vision, and emergent systems. Techniques identified as important include graph theory, game theory, data mining, evolutionary, combinatorial and cryptographic, routing and localized algorithms.

**Biography:** Ivan Stojmenovic received his Ph.D. degree in mathematics. He held regular and visiting positions in Serbia, Japan, USA, Canada, France, Mexico, Spain, UK (as Chair in Applied Computing at the University of Birmingham), Hong Kong, Brazil, Taiwan, and China, and is Full Professor at the University of Ottawa, Canada and Adjunct Professor at the University of Novi Sad, Serbia. He published over 250 different papers, and edited seven books on wireless, ad hoc, sensor and actuator networks and applied algorithms with Wiley. He is editor of over dozen journals, editor-in-chief of IEEE Transactions on Parallel and Distributed Systems (from January 2010), and founder and editor-in-chief of three journals (MVLSC, IJPEDS and AHSWN). Stojmenovic is one of about 260 computer science researchers with h-index at least 40 and has >10000 citations. He received three best paper awards and the Fast Breaking Paper for October 2003, by Thomson ISI ESI. He is recipient of the Royal Society Research Merit Award, UK. He is elected to IEEE Fellow status (Communications Society, class 2008), and is IEEE CS Distinguished Visitor 2010-12. He received Excellence in Research Award of the University of Ottawa 2009. Stojmenovic chaired and/or organized >60 workshops and conferences, and served in >200 program committees. He was program co-chair at IEEE PIMRC 2008, IEEE AINA-07, IEEE MASS-04&07, EUC-05&08-10, AdHocNow08, IFIP WSAN08, WONS-05, MSN-05&06, ISPA-05&07, founded workshop series at IEEE MASS, ICDCS, DCOSS, WoWMoM, ACM Mobihoc, IEEE/ACM CPSCom, FCST, MSN, and is/was Workshop Chair at IEEE INFOCOM 2011, IEEE MASS-09, ACM Mobihoc-07&08.

**Andreas F. Molisch**

**Title: Wireless propagation and its impact on wireless system design**

**Abstract:** Wireless propagation channels determine the fundamental performance limits of communications over the air. Furthermore, the propagation channels also determine the practical system performance of actual, deployable, systems. It is thus vital to establish models that are "as complicated as required to reproduce all RELEVANT effects, but no more complicated than that". As new systems and applications have emerged, what is "relevant" has changed significantly. Thus, the wireless propagation models we need today have to be suitable for wireless systems with large bandwidth, multiple antenna elements, and possibly operating in highly mobile environments. The talk will give an outline of the basic modeling principles for channel models that are suitable for modern systems, and will also show a few case studies that demonstrate the importance of realistic modeling.

A short discussion of standardization of channel models and application in system testing will conclude the talk.

**Biography:** Andy Molisch received the Dr. techn., and habilitation degrees from the Technical University Vienna (Austria) in 1994, and 1999, respectively. After working at AT&T (Bell) Laboratories, he joined Mitsubishi Electric Research Labs, Cambridge, MA, USA, where he rose to Distinguished Member of Technical Staff and Chief Wireless Standards Architect. Concurrently he was also Professor and Chairholder for radio systems at Lund University, Sweden. Since 2009, he is Professor of Electrical Engineering at the University of Southern California, Los Angeles, CA, USA. Dr. Molisch's current research interests are measurement and modeling of mobile radio channels, UWB, cooperative communications, and MIMO systems. He has authored, co-authored or edited four books (among them the textbook "Wireless Communications"), fourteen book chapters, more than 130 journal papers, and numerous conference contributions, as well as more than 70 patents and 60 standards contributions.

Dr. Molisch has been an editor of a number of journals and special issues, General Chair, TPC Chair, or Symposium Chair of multiple international conferences, and chairman of various international standardization groups. He is a Fellow of the IEEE, a Fellow of the IET, an IEEE Distinguished Lecturer, and recipient of several awards, most recently the IEEE's Donald Fink Award.

**Arun Somani**

**Title: Aggressive and Reliable High-Performance Architectures**

**Abstract:** As the transistor count on a chip goes up, the system becomes extremely sensitive to any voltage, temperature or process variations. One approach to immunize the system from the adverse effects of these variations is to add sufficient safety margins to the operating clock frequency. Timing Speculation (TS) provides a silver lining by providing better-than-worst-case systems. We introduce an aggressive yet reliable framework for energy efficient thermal control. We bring out the inter-relationship between power, temperature and reliability of aggressively clocked systems. We provide solutions to improve the existing power management

in chip multiprocessors to dynamically maximize system utilization and satisfy the power constraints within safe thermal limits. We observe that up to 75% Energy-Delay squared product savings relative to base architecture is possible.

**Biography**: Arun K. Somani is currently Anson Marston Distinguished Professor of Electrical and Computer Engineering at Iowa State University. Prior to that, he was a Professor in the Department of Electrical Engineering and Department of Computer Science and Engineering at the University of Washington, Seattle, WA and Scientific Officer for Govt. of India, New Delhi from. He earned his MSEE and PhD degrees in electrical engineering from the McGill University, Montreal, Canada, in 1983 and 1985, respectively.

Professor Somani's research interests are in the area of computer system design and architecture, fault tolerant computing, computer interconnection networks, WDM-based optical networking, and reconfigurable and parallel computer systems. He has published more than 250 technical papers, several book chapters, and has supervised more than 100 graduate students (35 PhD students). He is the chief architects of an anti-submarine warfare system for Indian navy, Meshkin fault-tolerant computer system architecture for the Boeing Company, Proteus multi-computer cluster-based system for US Coastal Navy, and HIMAP design tool for the Boeing Commercial Company.

He has served on several program committees of various conferences in his research areas, served as IEEE distinguished visitor and IEEE distinguished tutorial speaker, and delivered several key note speeches, tutorials and distinguished and invited talks all over the world. He received commonwealth fellowship for his post-graduate work from Canada during 1982-85, awarded Distinguished Engineer member of ACM, and elected a Fellow of IEEE for his contributions to “theory and applications of computer networks.”

**Nei Kato**

**Title: Robust and Efficient Stream Delivery for Application Layer Multicasting in Heterogeneous Networks**

**Abstract:** Application Layer Multicast (ALM) is highly expected to replace IP multicasting as the new technological choice for content delivery. Depending on the streaming application, ALM nodes will construct a multicast tree and deliver the stream through this tree. However, if a node resides in the tree leaves, it cannot deliver the stream to its descendant nodes. In this case, Quality of Service (QoS) will be compromised dramatically. To overcome this problem, Topology-aware Hierarchical Arrangement Graph (THAG) was proposed. By employing Multiple Description Coding (MDC), THAG first splits the stream into a number of descriptions, and then uses Arrangement Graph (AG) to construct node-disjoint multicast trees for each description. However, using a constant AG size in THAG creates difficulty in delivering descriptions appropriately across a heterogeneous network. In this talk, a new method, referred to as Network-aware Hierarchical Arrangement Graph (NHAG), to change the AG size dynamically to enhance THAG performance, even in heterogeneous networks, will be introduced. By comparing this new method to THAG and Split-Stream, the new method can be considered with better performance in terms of throughput and QoS. Meanwhile, some other related topics such as how to detect streaming content in high speed networks will also be touched upon.

**Biography:** Nei Kato received his M.S. and Ph.D. Degrees in information engineering from Tohoku University, Japan, in 1988 and 1991, respectively. He joined Computer Center of Tohoku University at 1991, and has been a full professor at the Graduate School of Information Sciences since 2003. He has been engaged in research on computer networking, wireless mobile communications, image processing and neural networks. He has published more than 200 papers in journals and peer-reviewed conference proceedings.

Nei Kato currently serves as the chair of IEEE Satellite and Space Communications TC, the secretary of IEEE Ad Hoc & Sensor Networks TC, the chair of IEICE Satellite Communications TC, a technical editor of IEEE Wireless Communications(2006~), an editor of IEEE Transactions on Wireless Communications(2008~), an associate editor of IEEE Transactions on Vehicular Technology(2009~). He has served as co-guest-editor for many IEEE journals and magazines, symposium co-chair for GLOBECOM’07, ICC’10, ICC’11, ChinaCom’08, ChinaCom’09, and WCNC2010-2011 TPC Vice Chair.

His awards include Minoru Ishida Foundation Research Encouragement Prize(2003), Distinguished Contributions to Satellite Communications Award from the IEEE Communications Society, Satellite and Space Communications Technical Committee(2005), the FUNAI information Science Award(2007), the TELCOM System Technology Award from Foundation for Electrical Communications Diffusion(2008), the IEICE Network System Research Award(2009), and best paper awards from many prestigious international conferences such as IEEE GLOBECOM, IWCMC, etc.

Besides his academic activities, he also serves as a member on the expert committee of Telecommunications Council, the special commissioner of Telecommunications Business Dispute Settlement Commission, Ministry of Internal Affairs and Communications, Japan, and as the chairperson of ITU-R SG4 and SG7, Japan. Nei Kato is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) and a senior member of IEEE.

**Yasushi Yamao**

**Title: An Intelligent WDN for Future Ubiquitous Society**

**Abstract:** Intelligence is an essential feature of advanced systems. The most important ability given by intelligence is adaptation, which keeps system performance high under the change of its environment. One of the interesting areas to apply intelligence is Wireless Distributed Network (WDN), which is an important technology of future ubiquitous society. Under the time-varying wireless environments that severely suffer from fading, quality control of multihop communication is a critical issue. This speech discusses how multi-hop communication quality in WDN can be maintained by the intelligence of distributed nodes that always watch surrounding node's behavior and take cognitive action. Cross-layer cooperation at each node enables real-time local path optimization including creation of bypass and shortcut paths. Packet communication quality improvements in terms of delivery ratio and delay are shown in some examples.

**Biography:** Dr. Yasushi Yamao received his B.S., M.S., and Ph.D. degrees in electronics engineering from Kyoto University, Kyoto, Japan, in 1977, 1979, and 1998, respectively.

He started his research career of mobile communications from the measurement and analysis of urban radio propagation as his M.S. thesis. In 1979, he joined the Nippon Telegraph and Telephone Corporation (NTT) Laboratories, Japan, where his major activities included leading research on GMSK modulator /demodulator and GaAs RF ICs for digital mobile communications, and development of PDC digital cellular handheld phones. In 1993, he moved to NTT DoCoMo Inc. and directed standardization of high-speed paging system (FLEX-TD) and development of 3G radio network system. He also joined European IST research programs for IP-based 4th generation mobile communication.

In 2005, he moved to the University of Electro-Communications as a professor of the Advanced Wireless Communication Research Center (AWCC). His current interests focus on wireless ubiquitous communication networks and protocols, as well as high-efficiency and reconfigurable wireless circuit technologies both in RF and Digital Signal Processing. He is a Fellow of IEICE and member of IEEE. He served as Vice President of IEICE Communications Society (2003-2004), Chairman of the

IEICE Technical Group on Radio Communication Systems (2006-2008) and Chief Editor of IEICE Communication Magazine (2008-2010). He is currently Vice Chairman of IEEE VTS Japan Chapter.

**Michael Small**

**Title: Complex Networks – Chaotic Dynamics**

**Abstract:** In the last decade, physicists and then biological scientists have found evidence of complex networks in a stunning range of physical and biological systems. In this talk, I will focus on a more basic, and possibly more interesting question: what can complex networks and the methods of complexity theory actually tell us about the dynamics underlying observed time series data?

A variety of methods have been introduced to transform time series data into complex networks. The complex network representation of the time series can then be used to gain new insight (information not readily available from other methods) about the underlying dynamics. We show that the structure of the complex network, and more specifically, the motif frequency distribution, depends on the nature of the underlying dynamics. In particular, low dimensional chaotic dynamics are associated with one particular class of complex network; and hyper-chaotic, periodic and stochastic motion are each associated with others. This complex network approach can then be used to identify the nature of the dynamics underlying a particular time series. Application of these methods will be demonstrated with several experimental systems: from musical composition, to sound production, and population dynamics.

**Biography:** Michael Small got his PhD in applied mathematics from the University of Western Australia, and then did post docs at UWA, Heroit-Watt University (Edinburgh) and Hong Kong Polytechnic University. Michael Small is now an Associate Professor in the department of Electronic and Information Engineering at the Hong Kong Polytechnic University. His research interests focus on complex systems and nonlinear time series analysis. His work emphasises the application of these methods in a diverse range of fields: disease propagation, neurophysiology, cardiac dynamics and many others. Workshop Chair at IEEE INFOCOM 2011, IEEE MASS-09, ACM Mobihoc-07&08.

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# Bifurcation of Limit Cycles in Two Given Planar Polynomial Systems

Xiao-Chun Hong and Qing-Hua Qin

**Abstract.** Bifurcation of limit cycles in two given planar polynomial systems is investigated by using both qualitative analysis and numerical exploration. The investigation is based on detection functions which are particularly effective for the perturbed planar polynomial systems. The study reveals that each of the two systems has 8 limit cycles. By using method of numerical simulation, the distributed orderliness of the 8 limit cycles is observed, and their nicety places are determined. The study also indicates that each of the 8 limit cycles passes the corresponding nicety point. The results presented here are helpful for further investigating the Hilbert's 16th problem.

**Keywords:** limit cycle, integrable non-Hamiltonian system, detection function, numerical exploration.

## 1 Introduction

During the past decades the bifurcation of limit cycles of the following planar polynomial system

$$\frac{dx}{dt} = P_n(x, y), \quad \frac{dy}{dt} = Q_n(x, y), \tag{1.1}$$

has been considerably investigated, and it has now become a very popular topic in the area of applied mathematics, where $P_n(x, y)$ and $Q_n(x, y)$ are two polynomials of degree $n$. It should be mentioned that the system (1.1) is related to the celebrated Hibert's 16th problem. For the perturbed Hamiltonian system

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$$\frac{dx}{dt} = -\frac{\partial H}{\partial y} + \varepsilon x R(x, y, \lambda), \quad \frac{dy}{dt} = \frac{\partial H}{\partial x} + \varepsilon y S(x, y, \lambda). \tag{1.2}$$

Li and Huang [1] showed that there are 11 limit cycles in a cubic Hamiltonian system under cubic perturbation $R(x, y, \lambda) = S(x, y, \lambda) = mx^2 + ny^2 - \lambda$ and obtained the Hilbert number $H(3) \geq 11$. Cao et al's study [2] indicated that there are 13 limit cycles in a cubic Hamiltonian system under seven-order perturbation $R(x, y, \lambda) = S(x, y, \lambda) = mx^6 + ny^6 - \lambda$. Tang and Hong [3] found that it exists 14 limit cycles in a cubic Hamiltonian system with nine-order perturbed term $R(x, y, \lambda) = S(x, y, \lambda) = mx^8 + ny^8 - \lambda$. Further, Hong and Qin [4] discovered that there are 15 limit cycles in a cubic Hamiltonian system with five-order perturbed term $R(x, y, \lambda) = S(x, y, \lambda) = mx^2 + ny^2 + kx^4 - \lambda$. For the perturbed Hamiltonian system

$$\frac{dx}{dt} = y, \quad \frac{dy}{dt} = x - x^3 + \varepsilon y(a_0 + a_1 x^2 + a_2 x^4 + a_3 x^6), \tag{1.3}$$

where $a_0$, $a_1$, $a_2$, $a_3$ and $\varepsilon$ ($0 < \varepsilon << 1$) are real parameters, Yang and Han [5] showed that the system (1.3) has 8 limit cycles.

From the above review, we found that most of previous studies focused on the system (1.2) with the perturbed terms being in the form of $R(x, y, \lambda) = S(x, y, \lambda) = mx^k + ny^k - \lambda$. In this paper, a different perturbed function $R(x, y, \lambda) = S(x, y, \lambda) = mx^2 + ny^2 + kx^2y^2 - \lambda$ is employed to explore the bifurcation behavior and the distribution of limit cycles for the two planar polynomial systems described in (1.4) and (1.5), where variables $m$, $n$, $k$, and $\lambda$ are used, rather than $m$, $n$, and $\lambda$ in the existing work.

Consider the following two perturbed planar polynomial systems

$$\frac{dx}{dt} = y, \quad \frac{dy}{dt} = x - x^3 + \varepsilon y(mx^2 + ny^2 + kx^2y^2 - \lambda), \tag{1.4}$$

$$\frac{dx}{dt} = y(x^2 + 1), \quad \frac{dy}{dt} = (x - x^3)(x^2 + 1) + \varepsilon y(mx^2 + ny^2 + kx^2y^2 - \lambda), \tag{1.5}$$

where $m$, $n$, $k$, $\lambda$ and $\varepsilon$ ($0 < \varepsilon << 1$) are all real variables.

Obviously, the system (1.4) is a cubic Hamiltonian system with quintic perturbed terms, whereas the system (1.5) is a quintic integrable non-Hamiltonian system with five-order perturbed terms. By using the method of detection function [1] and the method of numerical exploration [6], the bifurcation behavior of limit cycles in (1.4) and (1.5) is investigated in this paper. The investigation found that the detection functions are particularly effective for systems (1.4) and (1.5). The study indicates that, for the system (1.4), there are 8 limit cycles if $m = 1$, $n = 3.2$, $k = -3$, $0 < \varepsilon << 1$, 0.990091< $\lambda$ <0.996788, and for the system (1.5), there are also 8 limit cycles when $m = 1$, $n = 3.4$, $k = -3$, $0 < \varepsilon << 1$, 0.981178< $\lambda$ <0.996580.

## 2 Detection Functions and Detection Curves

In this section some preliminary results on the detection functions for perturbed Hamiltonian system are briefly reviewed. Let us begin with considering the perturbed Hamiltonian system. It is helpful to begin with introducing Ye's some useful results [7]. He obtained these results by introducing:

**Lemma 1.** Consider the perturbed Hamiltonian system

$$\frac{dx}{dt} = -\frac{\partial H}{\partial y} + P(x, y, \alpha)\,, \quad \frac{dy}{dt} = \frac{\partial H}{\partial x} + Q(x, y, \alpha)\,, \tag{2.1}$$

and the corresponding unperturbed Hamiltonian system

$$\frac{dx}{dt} = -\frac{\partial H}{\partial y}\,, \quad \frac{dy}{dt} = \frac{\partial H}{\partial x}\,. \tag{2.2}$$

Obviously system (2.1) reduces into system (2.2) when $P(x, y, 0) \equiv Q(x, y, 0) \equiv 0$. The curve $\Gamma^h$ defined by Hamiltonian $H(x, y) = h$ of system (2.2) is, then, closed orbits and will extend to the outside of $\Gamma^h$ as $h$ increases, and $\Gamma^h(D)$ is the area inside of $\Gamma^h$. If there exists $h^*$ such that the function

$$A(h) = \iint_{\Gamma^h(D)} [P''_{x\alpha}(x, y, 0) + Q''_{y\alpha}(x, y, 0)]dxdy\,, \tag{2.3}$$

satisfies $A(h^*) = 0$ and $A'(h^*) \neq 0$, $\alpha A'(h^*) < 0$ (>0), then system (2.1) has only one stable (unstable) limit cycle near to $\Gamma^{h^*}$ when $\alpha$ is very small. Conversely, if $\Gamma^h$ is constrained inside as $h$ increases, the stable properties of the limit cycle are opposite of that described above, i.e., when $\alpha A'(h^*) < 0$ (>0) the limit cycle is unstable (stable). If $A(h) \neq 0$, then system (2.1) has no limit cycle.

Li and Li [8] considered the following system:

$$\frac{dx}{dt} = -\frac{\partial H}{\partial y} - \mu x[p(x, y) - \lambda]\,, \quad \frac{dy}{dt} = \frac{\partial H}{\partial x} - \mu y[q(x, y) - \lambda]\,, \tag{2.4}$$

where $p(0,0) = q(0,0) = 0$. Using the results given in [7] above, it follows from $A(h) = 0$ that

$$\lambda = \lambda(h) = \frac{\iint_{\Gamma^h(D)} f(x, y)dxdy}{2\iint_{\Gamma^h(D)} dxdy}\,, \tag{2.5}$$

where $f(x, y) = xp'_x(x, y) + yq'_y(x, y) + p(x, y) + q(x, y)$.

The function $\lambda(h)$ is usually known as the detection function of system (2.4). Using the detection function $\lambda(h)$ and lemma 1 above, the following proposition regarding the limit cycle of system (2.4) can be obtained [9]:

**Proposition 1.** For any given $\lambda_0$: (i) If $(h_0, \lambda(h_0))$ is an intersecting point of the line $\lambda = \lambda_0$ and the detection curve $\lambda = \lambda(h)$, and $\lambda'(h_0)$ >0(<0), then the system (2.4) has only one stable (unstable) limit cycle near $\Gamma^{h_0}$ when $\lambda = \lambda_0$. (ii) If the line $\lambda = \lambda_0$ and the detection curve $\lambda = \lambda(h)$ have no intersecting point, then the system (2.4) has no limit cycle when $\lambda = \lambda_0$. Conversely, If $\Gamma^h$ is constrained inside as $h$ increases, the stability of the limit cycle is opposite to the results above.

The proof of this proposition can be found elsewhere [3,10]. For the sake of completeness, we briefly present the proof as below:

**Proof.** In Lemma 1, let $\alpha = -\mu$, $P(x, y, \alpha) = \alpha x[p(x, y) - \lambda]$, $Q(x, y, \alpha) = \alpha y[q(x, y) - \lambda]$. We have $P(x, y, 0) \equiv Q(x, y, 0) \equiv 0$ and $P''_{x\alpha} + Q''_{y\alpha} = f(x, y) - 2\lambda$.

Thus the $A(h)$ in Lemma 1 becomes

$$A(h) = \iint_{\Gamma^h(D)} f(x, y)dxdy - \lambda \iint_{\Gamma^h(D)} 2dxdy\,. \tag{2.6}$$

By denoting $\psi(h) = \iint_{\Gamma^h(D)} f(x, y)dxdy$ and $\phi(h) = \iint_{\Gamma^h(D)} 2dxdy$, we have $\lambda = \psi(h_0)/\phi(h_0)$, from $A(h_0) = 0$, which leads to

$$A'(h_0) = \psi'(h_0) - \lambda\phi'(h_0) = \frac{\psi'(h_0)\phi(h_0) - \psi(h_0)\phi'(h_0)}{\phi(h_0)}\,. \tag{2.7}$$

We also have from (2.5) that

$$\lambda'(h_0) = \frac{\psi'(h_0)\phi(h_0) - \psi(h_0)\phi'(h_0)}{[\phi(h_0)]^2}\,. \tag{2.8}$$

It is noted from (2.5) that $\phi(h_0) > 0$. Moreover, both $A'(h_0)$ and $\lambda'(h_0)$ have the same sign by comparing (2.7) with (2.8). Therefore, $-\mu A'(h_0)$ and $-\mu\lambda'(h_0)$ also have the same sign. From Lemma 1, the proof of Proposition 1 is thus completed.

## 3 Analysis of the Unperturbed Systems

Consider the unperturbed systems

$$\frac{dx}{dt} = y\,, \quad \frac{dy}{dt} = x - x^3\,. \tag{3.1}$$

$$\frac{dx}{dt} = y(x^2 + 1)\,, \quad \frac{dy}{dt} = (x - x^3)(x^2 + 1)\,. \tag{3.2}$$

The system (3.1) is a Hamiltonian system, whereas the system (3.2) is an integrable non-Hamiltonian system. The system (3.1) and the system (3.2) has three finite singular points, $O(0,0)$ is a hyperbolic saddle point, $A_1(1,0)$ and $A_2(-1,0)$ are two centers (see Fig. 1). The first integral of (3.1) and (3.2) is given by

$$H(x,y)=\frac{1}{2}y^2-\frac{1}{2}x^2+\frac{1}{4}x^4=h\ , \tag{3.3}$$

with integrating factor 1 and $\dfrac{1}{x^2+1}$ respectively.

From (3.3), we can get $h(\pm1,0)=-0.25$, $h(0,0)=0$, and

$$y_{\pm}=\pm u(h,x)=\pm\sqrt{2h+x^2-0.5x^4}\ .\quad(-0.25<h<+\infty) \tag{3.4}$$

Setting $y=0$, from (3.3), we can get

$$0.25x^4-0.5x^2-h=0\ .\ (-0.25<h<+\infty) \tag{3.5}$$

From (3.5), for an arbitrary constant of $h\in(-0.25,0)$, we can get definite $\pm x_1$ and $\pm x_2$; for an arbitrary constant of $h\in(0,+\infty)$, we can get definite $\pm x_2$.

As $h$ varies, the closed curves defined by (3.1) and (3.2) are as follows (see Fig. 1):

**(*A*)** $\{\Gamma_1^h\}$: $-0.25<h<0$. This is composed of two families of closed orbits surrounding the singular point $A_1$ or $A_2$ respectively.

**(*B*)** $\{\Gamma_2^h\}$: $0<h<+\infty$. This corresponds to a family of closed orbits which enclose all the three finite singular points.

Note that as $h$ increases, the curves $\{\Gamma_1^h\}$, $\{\Gamma_2^h\}$ extend outward.

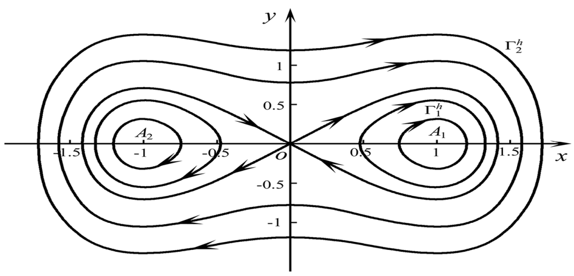


**Fig. 1** The phase portrait of unperturbed systems (3.1) and (3.2)

## 4 Distribution of Limit Cycles of the Perturbed Systems

We now consider the perturbed systems (1.4) and (1.5). Because some symmetry corresponds to three families of closed orbits in Fig. 1, using (2.3), we have

$$\iint_{\Gamma^h(D)}\left(\frac{\partial^2 P}{\partial x\partial\varepsilon}+\frac{\partial^2 Q}{\partial y\partial\varepsilon}\right)dxdy=0\ . \tag{4.1}$$

For the system (1.4), we can get

$$\frac{\partial^2 P}{\partial x \partial \varepsilon} + \frac{\partial^2 Q}{\partial y \partial \varepsilon} = mx^2 + 3ny^2 + 3kx^2y^2 - \lambda . \quad (4.2)$$

By considering (4.1) and (4.2), the detection functions $\lambda_j(h)$ ( $j = 1,2$ ) can finally be given in the form

$$\lambda_j(h) = \frac{\iint_{\Gamma_j^h(D)} (mx^2 + 3ny^2 + 3kx^2y^2)dxdy}{\iint_{\Gamma_j^h(D)} dxdy} . \quad ( j = 1,2 ) \quad (4.3)$$

Based on (4.3), the two detection functions of the system (1.4) can then be expressed as

$$\lambda_1(h) = \frac{\int_{x_1}^{x_2} x^2 u(h,x)dx}{\int_{x_1}^{x_2} u(h,x)dx} m + \frac{\int_{x_1}^{x_2} u^3(h,x)dx}{\int_{x_1}^{x_2} u(h,x)dx} n + \frac{\int_{x_1}^{x_2} x^2 u^3(h,x)dx}{\int_{x_1}^{x_2} u(h,x)dx} k , h \in (-0.25, 0) . \quad (4.4)$$

$$\lambda_2(h) = \frac{\int_{-x_2}^{x_2} x^2 u(h,x)dx}{\int_{-x_2}^{x_2} u(h,x)dx} m + \frac{\int_{-x_2}^{x_2} u^3(h,x)dx}{\int_{-x_2}^{x_2} u(h,x)dx} n + \frac{\int_{-x_2}^{x_2} x^2 u^3(h,x)dx}{\int_{-x_2}^{x_2} u(h,x)dx} k , h \in (0, +\infty) . \quad (4.5)$$

For $m = 1$ , $n = 3.2$ , $k = -3$ , from the (4.4) and (4.5), we can get detection curves $\lambda_1(h)$ and $\lambda_2(h)$ (see Fig. 2).

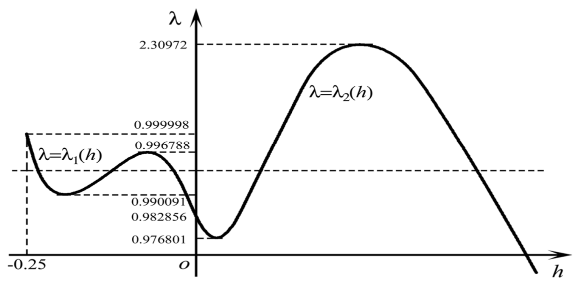


**Fig. 2** Detection curves of the system (1.4) when $m = 1$ , $n = 3.2$ and $k = -3$

For the system (1.5), we can get

$$\frac{\partial^2 P}{\partial x \partial \varepsilon} + \frac{\partial^2 Q}{\partial y \partial \varepsilon} = \frac{mx^2 + 3ny^2 + 3kx^2y^2 - \lambda}{x^2 + 1} . \quad (4.6)$$

By considering (4.1) and (4.6), the detection functions $\lambda_j(h)$ ( $j = 1,2$ ) can finally be given in the form

$$\lambda_j(h)=\frac{\iint_{\Gamma_j^h(D)}\frac{mx^2+3ny^2+3kx^2y^2-\lambda}{x^2+1}dxdy}{\iint_{\Gamma_j^h(D)}\frac{1}{x^2+1}dxdy}.\quad (j=1,2) \tag{4.7}$$

Based on (4.7), the two detection functions of the system (1.5) can then be expressed as

$$\lambda_1(h)=\frac{\int_{x_1}^{x_2}\frac{x^2u(h,x)}{x^2+1}dx}{\int_{x_1}^{x_2}\frac{u(h,x)}{x^2+1}dx}m+\frac{\int_{x_1}^{x_2}\frac{u^3(h,x)}{x^2+1}dx}{\int_{x_1}^{x_2}\frac{u(h,x)}{x^2+1}dx}n+\frac{\int_{x_1}^{x_2}\frac{x^2u^3(h,x)}{x^2+1}dx}{\int_{x_1}^{x_2}\frac{u(h,x)}{x^2+1}dx}k,\ h\in(-0.25,0). \tag{4.8}$$

$$\lambda_2(h)=\frac{\int_{-x_2}^{x_2}\frac{x^2u(h,x)}{x^2+1}dx}{\int_{-x_2}^{x_2}\frac{u(h,x)}{x^2+1}dx}m+\frac{\int_{-x_2}^{x_2}\frac{u^3(h,x)}{x^2+1}dx}{\int_{-x_2}^{x_2}\frac{u(h,x)}{x^2+1}dx}n+\frac{\int_{-x_2}^{x_2}\frac{x^2u^3(h,x)}{x^2+1}dx}{\int_{-x_2}^{x_2}\frac{u(h,x)}{x^2+1}dx}k,\ h\in(0,+\infty). \tag{4.9}$$

For $m=1$, $n=3.4$, $k=-3$, from the (4.8) and (4.9), we can get detection curves $\lambda_1(h)$ and $\lambda_2(h)$ (see Fig. 3).

Based on the results for the four detection functions shown in Figs. 2 and 3, following conclusions are presented:

**Proposition 2.** (i) For $m=1$, $n=3.2$, $k=-3$ and $0<\varepsilon<<1$, the system (1.4) has 8 limit cycles if 0.990091< $\lambda$ <0.996788 (see Fig. 4).

(ii) For $m=1$, $n=3.4$, $k=-3$ and $0<\varepsilon<<1$, the system (1.5) has 8 limit cycles too when 0.981178< $\lambda$ <0.996580 (see Fig. 5).

It should be mentioned that other results can be similarly obtained in addition to the case listed above. But we omit those details for conciseness.

For system (1.4), taking $m=1$, $n=3.2$, $k=-3$, $\lambda$ =0.995, $\varepsilon$ =0.001; for system (1.5), taking $m=1$, $n=3.4$, $k=-3$, $\lambda$ =0.99, $\varepsilon$ =0.001, using numerical exploration method [6], we find out the position of the each limit cycle of system (1.4) and system (1.5) depicted in Fig. 4 and Fig. 5 respectively.

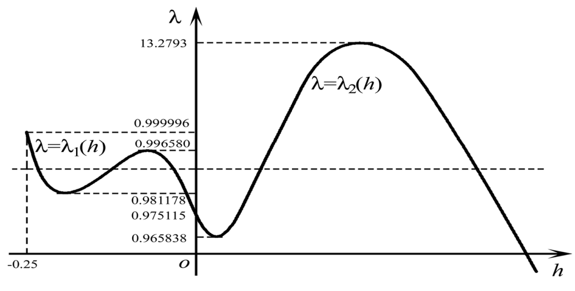


**Fig. 3** Detection curves of the system (1.5) when $m=1$, $n=3.4$ and $k=-3$

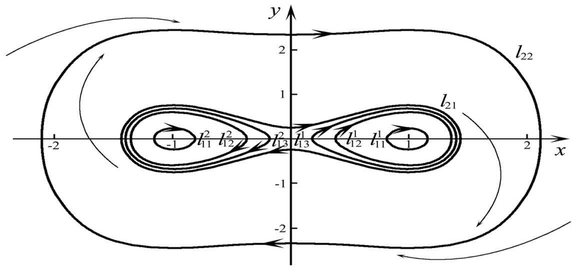


**Fig. 4** Eight limit cycles and their distribution for system (1.4) when $m=1$, $n=3.2$, $k=-3$, $\lambda$=0.995, $\varepsilon=0.001$. Stable limit cycles $l_{11}^i$ ( $i=1,2$ ), $l_{13}^i$ ( $i=1,2$ ) and $l_{22}$ pass (±0.8105,0) , (±0.1796,0) , (0,2.3409) respectively, unstable limit cycles $l_{12}^i$ ( $i=1,2$ ) and $l_{21}$ pass (±0.3748,0) , (0,0.2460) respectively.

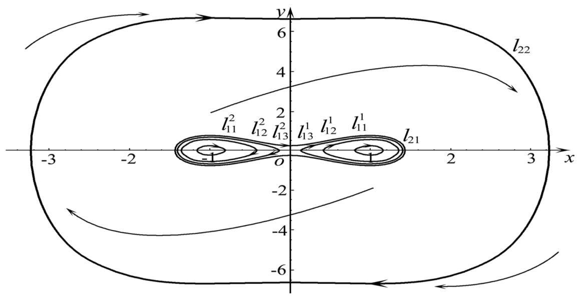


**Fig. 5** Eight limit cycles and their distribution for system (1.5) when $m=1$, $n=3.4$, $k=-3$, $\lambda$=0.99 and $\varepsilon=0.001$. Stable limit cycles $l_{11}^i$ ( $i=1,2$ ), $l_{13}^i$ ( $i=1,2$ ) and $l_{22}$ pass (±0.8088,0) , (±0.1289,0) , (0,6.5992) respectively, unstable limit cycles $l_{12}^i$ ( $i=1,2$ ) and $l_{21}$ pass (±0.4103,0) , (0,0.2315) respectively.

## 5 Conclusion

In the above discussion, we use both qualitative and numerical methods to investigate the number and distribution of limit cycles in two given planar polynomial systems (1.4) and (1.5). In particular, for the system (1.4), when $m=1$, $n=3.2$, $k=-3$ and $0<\varepsilon<<1$, the study reveals that it has 8 limit cycles if 0.990091< $\lambda$ <0.996788; for the system (1.5), when $m=1$, $n=3.4$, $k=-3$ and $0<\varepsilon<<1$, the study reveals that it has 8 limit cycles too if 0.981178< $\lambda$ <0.996580. It is also found that each limit cycle passes a particular point and the position of these points is obtained by using the numerical exploration method [6] when $\varepsilon=0.001$ for the particular value of parameter $\lambda$ =0.995 or $\lambda$ =0.99.

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