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МАКЕДОНСКА АКАДЕМИЈА НА НАУКИТЕ И УМЕТНОСТИТЕ
MACEDONIAN ACADEMY OF SCIENCES AND ARTS

ОДДЕЛЕНИЕ ЗА ТЕХНИЧКИ НАУКИ
SECTION OF TEHNICAL SCIENCES

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C O N T R I B U T I O N S

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ON THE EVE OF THE GREAT JUBILEE – 50 YEARS OF THE MACEDONIAN ACADEMY OF SCIENCES AND ARTS 1967 – 2017

This year the Macedonian Academy of Sciences and Arts (MASA) marks and celebrates a great jubilee – 50 years of existence and work of our highest institution in the field of sciences and arts. Although on 22 February 2017 the 50th anniversary of the enactment of MASA in the Assembly of the Socialistic Republic of Macedonia was marked, and on October 10 it will be 50 years since the solemn establishment of MASA, we proudly emphasize that our roots, the roots of the Macedonian and Slavic cultural and spiritual continuity, are far back, in a time dimension which is measured in centuries. Because the mission of the Ss. Cyril and Methodius, the historical events that made Ohrid, with the famous Ohrid Literary School, already in the IX century to become the center of the Slavic educational and enlightening activity, which then spread throughout all Slavic countries, have fundamentally changed our contribution to the treasury of the European culture and civilization. And furthermore, centuries later, in the middle of the XIX century the Macedonian revival began, with a pleiad of our cultural and national activists. These processes at the beginning of the XX century resulted in the establishment of the Macedonian Scientific and Literary Fellowship in Saint Petersburg, led by Dimitrija Chupovski and Krste Petkov Misirkov, whose rich scientific, literary and cultural activities were a significant reflection of our spiritual continuity and identity, and an event that has marked the dawn of the Macedonian Academy of Sciences and Arts. This continuity will remain in the period between the two world wars, with a pleiad of artists in literature, art, music, philological, economic, legal and technical sciences. A few years after World War II, in 1949, in free Republic of Macedonia, the first state University of “Ss. Cyril and Methodius” was established, within which, in less than two decades, solid personnel resources were created which allowed rapid development of the higher education and scientific activity in our country. It was an event of great importance for the establishment of MASA as the highest institution in the field of sciences and arts.

This millennium pace and continuity in the development of art and scientific thought in our region is an indication and evidence that we are not a nation without its own roots, without its own history, without its own culture, and that the attempts to deny our identity, language, name, no matter where they come from, are residual of the Balkan anachronisms, and essentially speaking, they are absurd and retrograde.

Immediately after the establishment of MASA followed a period of rapid development, diversification and enrichment of its scientific and research activities and artistic work. Almost two decades after the establishment MASA entered the phase of its maturity and has grown and has affirmed as the fundament of the Macedonian science, language, culture and history and as one of the pillars and symbols of the statehood of the Republic of Macedonia.

Today, MASA, according to its integral concept, structure and function, has all the necessary attributes of a modern national academy of European type, and of course, performs the three basic functions typical of the European national academies: creating communication space for confrontation of different views and opinions on important issues in the field of sciences and arts, scientific and research work and advisory role.

The scientific and research activities and artistic work, in fact, constitute the core of the activity of MASA. The number of completed scientific and research projects and projects in the field of arts within MASA is impressive – around 600 projects in the past 50 years. Some of these projects are long-term and are mainly related to the strategic issues of specific national interest, and significant is the number of fundamental and applied research in all fields of science and art represented in the Academy. MASA members in their scientific research increasingly incorporate the international dimension in the work – in the recent years more than 60% of the scientific papers have been published in international journals, most of which have been published in journals with impact factor; 50% of the papers that have been published in proceedings of scientific and professional meetings are related to meetings held abroad, etc. In addition, the works of our renowned writers and poets, members of MASA, are translated into foreign languages, and their work has found its place in world anthologies. Our prominent painters and sculptors of the older and the younger generation have created and create masterworks that are regularly exhibited at home and abroad. It should be particularly noted that our two research centers – Research Center for Energy and Sustainable Development and the Research Centre for Genetic Engineering and Biotechnology "Georgi D. Efremov", that have gained high reputation in the region and beyond, continue to successfully maintain the attained position. The work of the other research centers also enhances, including the newly established ones, which have begun to work on significant international scientific and research projects.

In its half-century of existence and work MASA developed a rich publishing activity. Since its establishment until today around 700 titles have been published – monographs, results of scientific projects, proceedings from scientific meetings, music releases, facsimile and jubilee publications, joint publications with other academies and scientific institutions, publications of solemn meetings, special issues of the departments of MASA etc. A special contribution to the publishing activities of MASA provides the "Trifun Kostovski" Foundation that has been existing and working for 18 years.

MASA proactively follows the changes and the new trends in the scope of the advisory function of the modern European national economies, and in that context the obligations arising from the project SAPEA - Science Advice for Policy by European Academies, initiated by the European Commission in order to intensify the cooperation of the European academies within their advisory role. Through the publication of the results of our scientific and research work, their presentation to the wider scientific and professional public in the country, to the government officials, etc., MASA participates in the policy-making in the field of sciences and arts and in the overall development of the country. The maintenance of the independence of MASA in carrying out the advisory role is our highest priority and principle.

In the recent years MASA has developed extensive international cooperation that contributes to the affirmation of the Macedonian scientific and artistic work and to the increasing of the reputation of MASA and of the Republic of Macedonia in international scale. Today, our Academy cooperates with more than 30 foreign academies and scientific societies and is a member of 7 international associations of academies. In the recent years the cooperation with the academies from the neighboring countries has been intensified, as well as with the Leibniz Society of Sciences from Berlin, and also, within the so-called Berlin process (Joint Science Conference of Western Balkans Process / Berlin Process) the cooperation with the German National Academy of Sciences – Leopoldina, with the French Academy of Sciences, the academies of Southeast Europe and others.

Due to the results achieved in its work, MASA and its members have won a number of high national and international awards. In the past 50 years, MASA has won around 90 awards and recognitions – charters, plaques, certificates of appreciation, medals and decorations from national and international scientific, educational, artistic and other institutions. Particularly, it should be noted that MASA has been awarded with the high decoration Order of the Republic of Macedonia for the contribution to the development of the scientific and research activity and artistic creativity of importance to the development and affirmation of the Macedonian science and state, which is awarded by the President of the Republic of Macedonia, as well as the prestigious Samuel Mitja Rapoport award of the Leibniz Society of Sciences from Berlin, which, for the first time, has been awarded to MASA. Today, 22 members of MASA have the status of foreign, corresponding and honorary members, as well as holders of honorary PhDs at around 60 foreign academies, scientific societies and universities.

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The developmental trajectory of MASA unambiguously confirms that the Academy, in its 50 years of existence and work, faced with periods of heights, but also periods of descents and turbulences that are most directly linked to the situation in the Macedonian society, i.e. with crisis periods of different nature – the dissolution of the former common state (SFR Yugoslavia), problems with the recognition of the international status of the country after its independence, the embargoes and the blockades of the country in the early transition years, the internal conflict in 2001 and the political crisis in the last two-three years. In such crises and tense periods the criticism for the Academy grew – that MASA is an institution closed in itself, that MASA stays away from the current issues and developments in the country, and so on. On the one hand, it is a result of the insufficient understanding of the social role of the Academy – MASA is the highest scientific institution, where hasty reactions of columnist 'type', with daily political features are not characteristic. On the contrary, MASA uses facts and arguments. The basic activity of MASA, the results achieved in the scientific research and the artistic work is our identification within the national and international professional and scientific community, and beyond, within our society. On the other hand, this criticism and perception of MASA has a real basis in the fact that MASA, as opposed to the huge opus of implemented scientific and research and artistic projects still insufficiently affirms the results of its scientific and artistic production to the public. It is our weakness that we must overcome in the future. Of course, we cannot and must not "turn a blind eye" to the other weaknesses and omissions which, at least from time to time, we have faced with over the past 50 years and which we will face with in the future – insufficient scientific criticism of the events in the field of sciences and arts, insufficient resistance to political influence etc. On the contrary, in the future, we will have to clearly identify the weaknesses and the oversights in our work and to find out the right approaches to overcome them.

Today we live in a world of great science. The strong development of sciences, the new technological model based on information and communication technologies, the new wave of entrepreneurial restructuring of economies and societies, the globalization of the world economic activity, opened new perspectives to the economic growth and the development of individual countries and of the world economy as a whole. However, these processes, by their nature, are contradictory. The latest global financial and economic crisis of 2007-2009 revealed the contradictions of the globalization and the discontent of the people from it – the uneven distribution of wealth and power among individual countries, destruction of the resources and the environment worldwide, exhaustion of power of the existing technology and development models. These processes resulted in other problems – refugee and migration crises, strengthening of the regional and national protectionism despite the efforts to liberalize the international trade, fencing of the countries with walls at the beginning of the new millennium, changes in the economic and technological power and of the geo-strategic position and importance of entire regions and continents, etc. Nevertheless, one thing is a fact – societies that aspire to grow into societies and knowledge-based economies more easily deal with all the above mentioned problems, challenges and risks of the modern world. Of course, moving towards a development knowledge-based model assumes large investments of resources in education, science, research and development and in culture, simultaneously accompanied by well-conceived and devised strategies on development of these crucial areas of the human spirit and civilizational endurance. Hence, this fact, undoubtedly, emphasizes the special significance of the national academies of sciences and arts in achieving this objective.

In the recent years the Republic of Macedonia has been facing with the most difficult political and social crisis in the period after its independence. We are facing a crisis of the institutions, breach of the principles of the rule of law, the phenomenon of "captured state", a decline in the process of democratization of the society and falling behind on the road to the Euro-Atlantic integration processes. The problems that are now in the focus of our reality will require major reforms, much knowledge, energy and political will to overcome them. In this sense, and in this context, the role of MASA and of the overall scientific potential of the country in overcoming the crisis is also particularly important.

The above summarized evaluations and considerations about the development of MASA in the past 50 years, about the achievements in the realization of its basic activity, about the problems it faced and faces with, about the major challenges arising from the new age and which are determined with the changes in the international and national environment, they alone define the main priorities of our Academy in the forthcoming period:

- Our long-term goals are contained in the mission and vision of MASA as the highest institution in the field of sciences and arts. The mission of MASA is through the development of the basic functions that are characteristic for all modern national academies of European type, to give its full contribution to the inclusion of the Macedonian science and art in the modern European and world trends, and our vision is the Republic of Macedonia to become an advanced society based on science and knowledge;
- In the forthcoming years the focus of the scientific and research activity and artistic work of MASA, in cooperation with the other scientific and research institutions in the country and with government experts, will be particularly

focused on the elaboration of issues and topics that are most directly related to the sources of the current political and social crisis in the country in order to offer possible solutions, approaches and policies to overcome it;
- The issues related to the Euro-Atlantic integration processes of the Republic of Macedonia, their continuous and persistent scientific monitoring and elaboration and active participation of MASA members in the preparation for the accession negotiations with the EU will remain a high priority on the agenda of MASA. Our ultimate goal is the Republic of Macedonia to become a democratic, economically prosperous and multicultural European country.
- The increasing incorporation of the international dimension in the scientific and artistic work of MASA, through the cooperation with foreign academies, scientific societies and other scientific institutions, through application and work on scientific projects financed by the European funds and the funds of other international financial institutions, also remains our important priority.

Let us congratulate ourselves on the great jubilee – 50 years of the Macedonian Academy of Sciences and Arts.

БИБЛИОГРАФИЈА НА АКАДЕМИК ЉУПЧО КОЦАРЕВ

(ПО ПОВОД НЕГОВИОТ 60. РОДЕНДЕН)

ЛЕОНИД ГРЧЕВ

Во периодот од 1986 година до 2015 година – период од 30 години – академик Љупчо Коцарев публикувал 134 публикации во списанија со фактор на влијание, повеќе од 10 публикации во (меѓународни и домашни) списанија без фактор на влијание, и повеќе од 150 публикации во зборници на рецензирани трудови од (меѓународни и домашни) конференции. Тој бил уредник на 6 книги и автор на 6 патенти (одобрени во САД и/или Европа). Неговите публикации се цитирани според Web of Sceince (Science Citation Index) 6.384 пати (6.133 **без себецитирање)**, додека според Google Scholar тие се цитирани 11.248 пати (податоци од 25 октомври 2015 година). Според статистиката што ја води издавачот Elsevier, статиите публикувани во Elsevier се видени/пристапени преку порталот на издавачот 18.946 пати (податоци до септември 2015 година). Според статистиката што ја води издавачот Springer, вкупниот број преземени (dowload) текстови од книгите што ги уредувал акад. Коцарев е 36.500 (податоци заклучно со 2014 година). Табела 1 и Табела 2 ја прикажуваат распределбата на публикациите во списанија со фактор на влијание по години и по списанија/издавачи, соодветно. Академик Коцарев соработувал со истражувачи од многу земји, вклучувајќи ги САД, Русија, Кина, Јапонија, Германија, Италија, Шпанија, Полска, Унгарија, Велика Британија, Австралија, Данска, Холандија, Франција, Канада, Мексико и многу други.

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Распределба по години

1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	**To-tal**
1	2	1	0	1	0	3	7	4	5	**24**

1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	**Total**
12	10	3	2	4	7	4	2	4	7	**55**

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	**Total**
6	5	5	4	6	6	4	3	11	5	**55**

Списание (издавач)	Број на публикации
Advances in Protein Chemistry and Structural Biology (Springer)	1
Chaos: An International Journal of Nonlinear Science (American Institute of Physics)	4
Chaos, Solitons, and Fractals (Elsevier)	6
Chemical Physics (Elsevier)	1
Circuits; Systems and Signal Processing (Springer)	1
Cognitive processing (Springer)	1
Communications in Nonlinear Science and Numerical Simulation (Elsevier)	4
Electronics Letters (The Institution of Engineering and Technology, England)	1
Energy (Elsevier)	1
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Geophysical Research Letters (Wiley)	1
IEEE Circuits and Systems Magazine (IEEE, USA)	1
IEEE Communication Letters (IEEE, USA)	1
IEEE Network (IEEE, USA)	1
IEEE Transaction on Circuits and Systems (IEEE, USA)	23
IEEE Transactions on Industrial Electronics (IEEE, USA)	1
IEEE Transaction on Information Theory (IEEE, USA)	1
IEICE Transactions on Fundamentals and Electronics, Communications and Computer Science (The Institute of Electronics, Information and Communication Engineers, Japan)	1
International Journal of Bifurcation and Chaos (World Scientific)	18
International Journal of Circuit Theory and Application (Wiley)	1
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Nonlinear Processes in Geophysics (European Geosciences Union)	2
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Physical Review B (American Physical Society)	1
Physical Review Letters (American Physical Society)	7
Physics Letters A (Elsevier)	16
PLoS ONE (Public Library of Science)	2
Scientific Reports (Nature)	2
Z. Angew. Math. Mech (Wiley)	1
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SPECIAL CASES OF NETWORK INFERENCE FROM INFECTION STATISTICS

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Abstract: Following our recent work on inferring network topology from infection statistics [1], in this paper we analyze two special cases to which the methodology presented in [1] can be applied with improved efficiency. In the first case we suggest and analyze the use of discriminators when it is known that the observed network is unweighted. Next, we analyze the case where the physical topology of a weighted network is known (there is a prior knowledge about how nodes are connected) and we need to determine link weights. In both cases, significant improvement in times required for proper assessment of the network topology is obtained, compared to the general case. The results suggest that the methodology presented in [1] is of practical use in cases where we have some prior knowledge about the network structure.

1. Introduction

The topic of inference of the elements of networked structures, as a subdomain of a broader set of problems, dealing with discovering underlying mechanisms that drive complex systems, has been of particular interest in the last few years. This, followed the decade in which studies of complex networks were considered as of at-most importance. The interest in complex networks, and phenomena related to them, though not new, was raised primarily by the emergence of the Internet and its by-products, mostly the social networks and network applications. Scientists were suddenly able to observe in real-time how new and different forms of networks (technical and social) were forming, followed by spontaneous development of dynamical processes taking place on them. Parallels between natural forms and technical networks were drown and the research of vast variety of natural and social networked structures and phenomena blossomed. Major achievements were made in the study of brain networks [2, 3, 4, 5], epidemic spreading processes [6, 7, 8, 9], gene and protein networks. In parallel, methods and models giving more detailed insight were developed , as well as control algorithms suggested dealing with spontaneous and emerging phenomena in technical structures, like cascading failures and blackouts of the infrastructure grids [10, 11, 12, 13, 14].

In that context, research related to inference of network topology, as an inverse problem, was a natural extension to the on-going work in the field of complex networks. Recently, number of works addressed the issue. Most of them were focused on the inference of gene-regulatory networks [15, 16, 17, 18, 19], where network inference is a natural step that precedes the analysis. Similar statement is valid for the brain networks as well [20, 21, 22]. Finally, number of works dealt with inference of network topology from more theoretical setups [23, 24, 25, 26, 27, 28, 29].

In this article, following our recent work [1] , we study inference of network links from infectious statistic for some special cases. In [1], we suggested methodology and developed an algorithm for inference of network topology (link weights) from infectious statistics, providing that the number of nodes and the characteristics of the observed infectious process are known. Though the obtained result is exact, in practice, the time necessary for proper assessment of link weights by the suggested algorithm is excessive. The reason for this lyes in the huge statistical sample necessary for convergence of the statistical means. In the conclusion of [1], we mentioned that the method and the implementation algorithm may be adjusted to give results in significantly shorter times, in networks for which we have some prior knowledge. In what follows, We present the results of that study.

2. Previous work

In our previous work [1], We have considered the following problem: given a network for which we know only the number of nodes and their infection status at each instance, to determine the network topology. The observed network is supposed to be weighted and, in general case, unsymmetrical.

The results were obtained for a SIS type of infection with known β

and δ parameters. We used the standard definition for the SIS process, as described in [30, 31, 32, 33, 34, 35, 36, 37]. Due to specifics in the problem definition, we described the SIS infection with a status difference equation:

$$\begin{aligned} s_i(t+1) &= (1-s_i(t))\left(1-\prod_{\substack{j=\overline{0,N-1}\\ j\neq i}}(1-a_{ij}(t)\beta_{ij}(t)s_j(t))\right) \\ &+ s_i(t)(1-\delta_i(t)) \end{aligned} \tag{1}$$

In (1) $s_i(t)$ represents the status of node i at the instance t, with $s_i(t) = 0$ denoting that the node is susceptible and $s_i(t) = 1$ that the node is infected.

Network links are represented with the random $\{0, 1\}$ functions $a_{ij}(t)$. The value $a_{ij}(t) = 1$ denotes that node i is connected to node j at time t and may be influenced (among other be infected) by it. It is important to emphasize that the influence denoted by $a_{ij}(t)$ is only in the direction from node j to node i (the reverse influence is denoted by $a_{ji}(t)$) . We consider that the rate of contact denoted by these functions follow the normal operating patterns of the network. The occurrence of infection is only a by-product of these normal patterns. The rate of influence is denoted by the expectation $\omega_{ij} = E[a_{ij}(t)]$ and is called weight. In other words, the weights represent the fraction of time in which node j influences node i (is connected to). Networks following this link-behavioral pattern are known as temporal networks. For details regarding the temporal networks we refer the readers to [38, 39, 40]

The terms $\beta_{ij}(t)$ are $\{0, 1\}$ random functions that define whether a susceptible node i when in contact only with an infected node j will become infected, in the time-frame $[t, t + 1]$. We consider (and this is generally accepted approach when studying spreading processes) that expectation values (means in time) of $\beta_{ij}(t)$'s are equal for all $i \neq j$, i.e $\beta_{ij} = E[\beta_{ij}(t)] = \beta$. The parameter β is known as "infection rate". In the same manner, the random functions $\delta_i(t)$ denote whether an infected node i will overcome the infection and become susceptible in the time-frame $[t, t + 1]$. It is custom to call their expectation values $\delta = \delta_{ij} = E[\delta_{ij}(t)]$ curring rate.

Relation (1) is a $\{0, 1\} \to \{0, 1\}$ mapping that describes the status change of each particular node as function of time and therefore exactly describes the SIS process. Though it may be rarely seen in the literature, it is only an adapted algebraic relation derived from logical expression that defines the SIS process.

Starting from (1), and after a complicated mathematical procedure, We have derived the following relation for the weight of each individual link [1]:

$$w_{ij} = \frac{1}{\beta}\left(1 - \frac{1 - E[X_i^{t+1}|\overline{X_i^t}X_j^t Y_{n,i,j}^t]}{1 - E[X_i^{t+1}|\overline{X_i^t}\ \overline{X_j^t} Y_{n,i,j}^t]}\right) \tag{2}$$

In (2), $\overline{X_i^t}$ denotes the logical event: node i is susceptible at time t (consequently X_i^t denotes: node i is infected at time t). The term $Y_{n,i,j}^t$ denotes a logical joint event that describes the infection status of all nodes in the network, except nodes i and j. For example: let $i = 0$, $j = 1$, and $N = 5$. Event $Y_{n=5,0,1}^t = X_2^t\overline{X_3^t}X_4^t$ is a join infection event that describes the status of nodes 2, 3 and 4, stating: at time t node 2 is infected, node 3 is not infected, node 4 is infected. Index n is a variation index, which value ranges between $n = 0$, for the joint event in which all considered nodes are susceptible and $n = 2^{N-2} - 1$ for the joint event where all considered nodes are infected. In the variation count we use lexicographical ordering in which position of each node is determined by its index i in descending order. In our example the lexicographical ordering is $2 \succ 3 \succ 4$, so the variation index is $n = 1_2 \times 2^2 + 0_3 \times 2^1 + 1_4 = 5$.

In the further text we will often disregard the index t, when discussing the infection events as repetitive. We will use the index only when we would like to explicitly connect the events with time t.

For practical implementation, it is sufficient to chose and observe only one of the joint events $Y_{n,i,j}$. In [1] we suggest a method how to approximately determine $Y_{n,i,j}$ (i.e. n) that is expected to have a very high repeatability, and use that event for observation. We call this event "particular event" and denote it with $Y_{p,i,j}$. For details regarding the derivation of equation (2), practical implementation of the obtained result and the terminology used, we refer the readers to [1].

In [1], we argued that though expression (2) is exact, the suggested implementation algorithm is in general impractical, since it requires huge amount of time for proper assessment. This is due to two reasons: large statistical sample necessary to achieve the desired accuracy and the low repeatability of the particular event. As a method to improve on the repeatability of $Y_{p,i,j}$ in [1] we have suggested a modified form of the original implementation algorithm, that we named Virus Overload (VO). This variant understood that the network is overloaded by different types of viruses (or distinguishable strains of the same virus) with identical viral characteristics β and δ. This is an artificial methodology that may be implemented only on technical networks.

The results of the analysis of the VO methodology suggested significant improvement compared to the original approach, however the required assessment times were still unsatisfactory. In the articles Conclusion we have stated that, repeatability of the particular event (that determines how fast the required statistical sample may be collected) may be further improved in some special cases. In the next section we consider some of these special cases.

3. Problem definition

In this article, We analyze the method and algorithm presented in [1] in two special cases in which we have some a priori knowledge about the network itself. In the first case, we know that the network under observation is unweighted (purely topological network) and we need to find which links exist. In the second we know the underlying topological structure i.e which links exist, but we know nothing about the weights of those links. In what follows, We give a brief description of the application of the methodology presented in [1], with an adequate adaptation, for these two cases.

3.1. Unweighted networks

Since the unweighted networks have link weights that are either $\omega_{ij} = 0$ or $\omega_{ij} = 1$, the method presented in [1] and the expression given with (2) may be adapted with the use of discriminators. Let ω_{ij}^{τ} be the estimate of the link weight ω_{ij} at time of observation τ obtained using the relation (2). We define $\omega_{ij}^{\tau,d}$ as an estimation of the link weight after the use of the dicriminator as:

$$\omega_{ij}^{\tau,d} = \begin{cases} 0, & \text{if } L_0 < \omega_{ij}^{\tau} < R_0 \\ 1, & \text{if } L_1 < \omega_{ij}^{\tau} < R_1 \end{cases} \tag{3}$$

In (3) L_1 and R_1 define the lower and the upper limit of ω_{ij}^{τ} for which the discriminator will decide that the link (i, j) exists. The same stands in regard to L_0 and R_0 and the decision that a link does not exist. Though it is customary to set similar type of discriminators using simple thresholds (usually $L_0 = -\infty$, $R_0 = L_1 = 0.5$, $R_1 = +\infty$), we suggest more complex discriminator form. The reason for this is that in the early stages of assessment use of simple discriminator may lead to wrong conclusion and a premature termination of the assessment process.

3.2. Known topological structure

In this case we have a major advantage in comparison to the general case. In [1], an assumption is made in the derivation of the equation (2) that all nodes in the network are potentially connected among each other (full mesh). This is a natural hypothesis, since no knowledge exists about which nodes are neighbors of an arbitrary node i, and therefore influence it (may infect it). Then it is expected that the assessment process determines weather this assumption is true or not, by producing values $\omega_{ij} = 0$ if nodes i and j are not connected. In mathematical terms, this resulted in a very complex form of the join events $Y_{n,i,j}$ (as well as the particular event $Y_{p,i,j}$) that comprised of the statuses of all nodes in the network (except i and j).

If the topological structure is known, there is an a priori knowledge about which nodes may influence (infect) an arbitrary node. Therefore, the initial full mesh hypothesis may be dismissed. In the alternative derivation procedure (omitted due to the identical form of the one presented in [1]) the joint events $Y_{n,i,j}$, comprise only of the statuses of nodes that are neighbors of node i. In practical terms this results in much higher repeatability of the particular event. Furthermore, this repeatability is highly correlated with the node degree d_i. To illustrate this, consider $d_i = 1$; then $Y_{p,i,j}$ is an empty event and may be considered to repeat in every step of the infection dynamics. For $d_i = 2$, $Y_{p,i,j} = X_k$ or $Y_{p,i,j} = \overline{X_k}$ (whatever is more probable), where k is the second neighbor of node i, besides node j; the repeatability of the $Y_{p,i,j}$ is max($E[X_k]$, $E[\overline{X_k}]$) per time step. Since the size of the statistical sample for given time period T is proportional to the repeatability of $Y_{p,i,j}$, the time required for collecting a sufficient amount of data for proper assessment of a link weight is now much shorter. This especially refers to links leading to (in-links) nodes with small node degrees.

As may already be seen, the assessment of each in-link may be performed individually, and without any knowledge about the rest of the network. In that sense, this methodology may be adapted to cases where only segments of a larger network should be inferred.

4. Materials and tools

To evaluate the suggested methodology adaptation, as well as to compare it with the results obtained in [1], in this article we analyze the special cases described in Section 3, on the same networks used in [1]:

- unweighted Barabási−Albert network [41] (UBA, $N = 30$, $m_0 = 3$, $m = 2$);
- unweighted Watts−Strogatz network [42] (UWS, $N = 30$,$r = 3$, $p = 0.2$);
- unweighted Erdös−Rényi network [43] (UER, $N = 30$, WS algorithm [42] with $r = 3$, $p = 0.9$);
- weighted Barabási−Albert network (WBA derived from the UBA network by adding random link weights);
- weighted WattsStrogatz network (WWS derived from the UWS network by adding random link weights);
- weighted Erdös−Rényi network (WER derived from the UER network by adding random link weights);

As stated in [1], the unweighted networks are symmetrical. However, this does not impact the generality of the result in the unweighted case, since each direction (in-link) is treated separately. In the weighted case, the symmetry is lost, due to assignment of different weights for each link direction.

In the same context, as tools for evaluation of the obtained results, we use functions similar to those suggested in [1]. However, due to the specific changes in the circumstances under which the network topology is inferred, we make adequate adaptations.

For the case where we use discriminators, we define two new estimation functions:

- fraction of Correctly Identified Links- $CIL(\tau)$;
- fraction of UnIdentified Links- $UIL(\tau)$;

For the case of known physical topology, we adapt almost identical error functions (EF) and precision estimation functions (PEF) as described in [1], with the necessary correction for the normalization factor, that is now L, rather then $N(N-1)$, with L being the number of links.

The EF considered are defined as:

- Mean absolute error - $mae(\tau) = \frac{1}{L}\sum_{i=0}^{N-1}\sum_{\substack{j=0\\ j\neq i}}^{N-1}\|w_{ij} - w_{ij}^{\tau}\|$;
- Maximal absolute error for an existing link - $xae1(\tau) = max_{i\neq j, w_{ij}\neq 0}\|w_{ij} - w_{ij}^{\tau}\|$;

The PEFs are defined with:

$$k_i(\tau) \quad = \quad \frac{\sum_i \sum_{j,j\neq i} \delta(a_i < \|w_{ij} - w_{ij}^{\tau}\| < b_i)}{L}$$

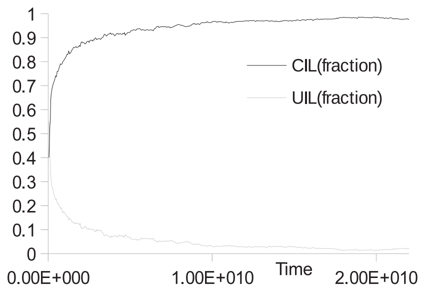
where $a_i = 10^{-i}$ for $i = 1, 2, 3$, $a_4 = 0$, $b_i = 10^{-i+1}$ for $i = 2, 3, 4$, $b_1 = \infty$.

5. Results

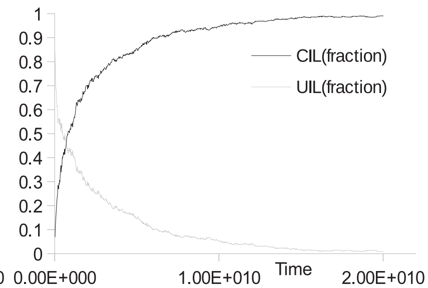
5.1. Discriminator method

In the analysis of the roll of discriminators on the quality of assessment for the unweighed networks, the original time series obtained in [1] were used, except for the case of the UBA graph (in the original work virus overload method was utilized for this graph). Parts of the obtained time assessments were run trough discriminator with following parameters: $L_0 = -0.3$, $R_0 = 0.3$, $L_1 = 0.7$, and $R_1 = 1.3$. The results of the analysis are presented in Fig.1.

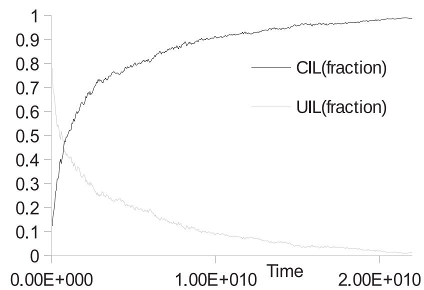
The results in all three cases show that almost all links are recognized within a time-frame of approximately 2×10^{10} cycles. Simultaneously, the fraction of unrecognized links approaches zero within the same time frame. This is an improvement compared to the results given for the same networks in [1]. The improvement is expected, since the detection errors in the results presented in [1] were mainly small and equally distributed around the expected means. However, the time required for the assessment is still excessive and , further more, grows with the size of the network.



(a) UBA, $\beta = 0.2$, $\delta = 0.1$, CIL/UIL



(b) UWS, $\beta = 0.2$, $\delta = 0.1$, CIL/UIL



(c) UER, $\beta = 0.1$, $\delta = 0.1$, CIL/UIL

Figure 1: Time evolution of $CIL(\tau)$ and $UIL(\tau)$ for the unweighted networks, when discriminator is used in the assessment process.

5.2. Known physical topology

The results of the analysis of the implementation of the methodology and the algorithm in cases where the physical topology is known, are presented in Figures 2 and 3.

As can be seen from the figures, there is a major improvement in regard to assessment times, compared to the general case [1]. To illustrate this, in Table. 1 we compare times required to reach certain values (marks) of both $mae(t)$ and $xae1(t)$ in the general case and the case where the physical topology is known.

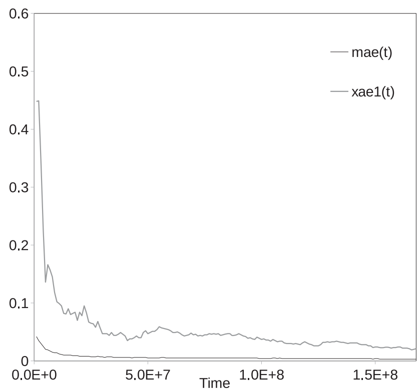
Network	$mae(t)$ time/mark	$xae1(t)$ time/mark
WBA general	$2 \times 10^{11}/0.01$	$2 \times 10^{11}/0.1$
WBA known	$1.3 \times 10^{7}/0.01$	$1.1 \times 10^{7}/0.1$
WWS general (VO 200)	$2.2 \times 10^{9}/0.02$	$10^{9}/0.1$
WWS known	$7 \times 10^{7}/0.02$	$8 \times 10^{7}/0.1$
WER general (VO 200)	$1.4 \times 10^{9}/0.01$	$1.4 \times 10^{9}/0.05$
WER known	$3 \times 10^{7}/0.01$	$6.1 \times 10^{7}/0.05$

Table 1:

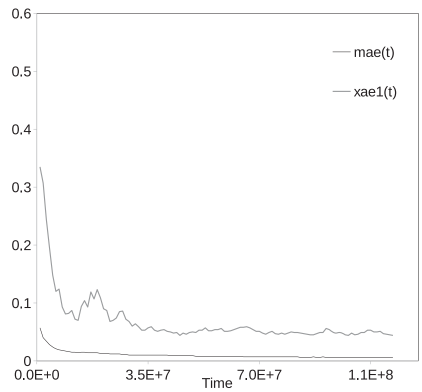
As may be seen from the table, the improvement in the assessment times varies in the 10^3-10^4 fold range (the results for WWS and WER in [1] were obtained for VO algorithm which gave a 200 fold improvement in regard to the standard algorithm). Major improvement may be seen for the WBA graph. This comes as no surprise: Barabasi-Albert graph is characterized by a large number of nodes with small node degrees. Using the newly adapted methodology, assessment of the nodes with small node degrees is fast. For those nodes the particular event is uncomplicated: it consists only of few or even no (node degree 1) joint events. Therefore, its repeatability is much higher, compared to the general case [1].

6. Conclusion

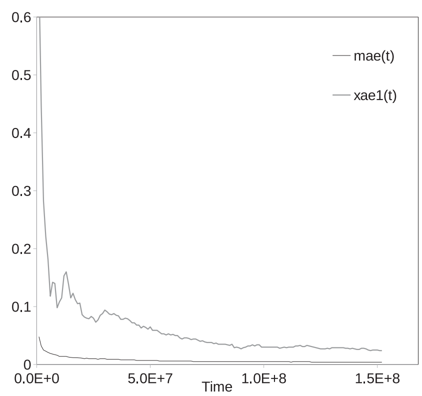
In this article, we have analyzed two special cases in which given some prior knowledge about an unknown network, we can utilize assessment methodology described in [1] with improved efficiency. In the first case, we considered networks that are known to be unweighted, and suggested use of discriminators. In the second we have observed the case, where the physical topology



(a) WBA, $\beta = 0.4$, $\delta = 0.1$, EF

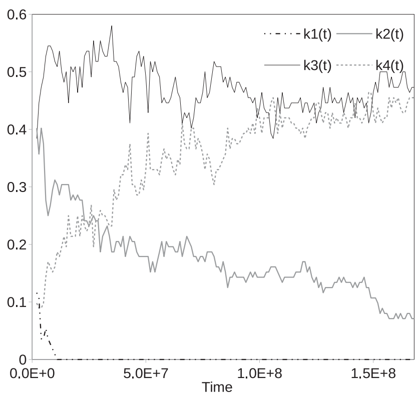


(b) WWS, $\beta = 0.2$, $\delta = 0.1$, EF

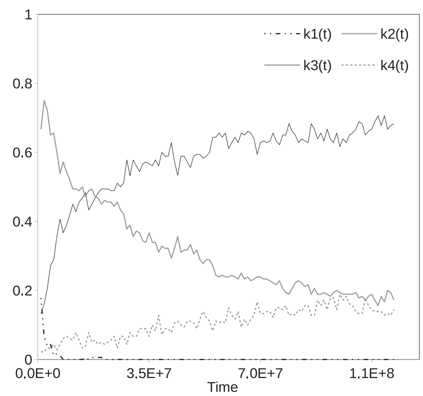


(c) WER, $\beta = 0.2$, $\delta = 0.1$, EF

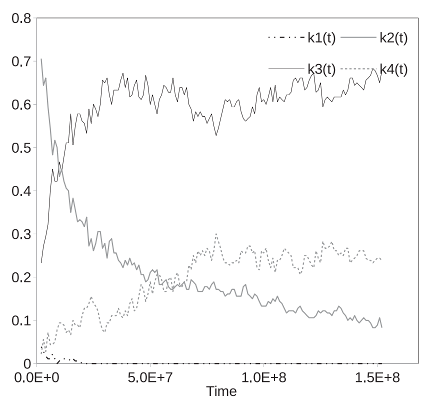
Figure 2: Time evolution of EF obtained from the simulations performed on the unweighted networks in case of a priori known physical topology



(a) WBA, $\beta = 0.4$, $\delta = 0.1$, PEF



(b) WWS, $\beta = 0.2$, $\delta = 0.1$, PEF



(c) WER, $\beta = 0.2$, $\delta = 0.1$, PEF

Figure 3: Time evolution of PEF obtained from the simulations performed on the unweighted networks in case of a priori known physical topology

of a network is known. It was shown that simple redefinition of the joint events $Y^t_{n,i,j}$, and therefore the particular event $Y^t_{p,i,j}$, significantly improved the assessment time.

One should consider that in most networks, even in the presented cases, the infectious dynamics is insufficiently fast, compared to real-time processes occurring in those network. Therefore, proper assessment can not be made in, what would considered to be, ”normal” time frame, using these methods alone. Combination of the presented algorithms with the VO approach, will lead to further improvement, especially in the case where the physical topology is known. Providing that the maximal node degree of the observed network is low to moderate (bellow 20), combination of the methodology presented in Section 3.2 and VO may be used for measurement of mid-term network activity, regardless of the size of the network. However, one should bare in mind that, as stated in [1], use of VO would in practice affect the network dynamics as well, so proper correction terms should be considered.

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FREE DAMPED TORSIONAL VIBRATIONS OF CANTILEVER BEAM STRUCTURE

Abstract

In this paper are analysed free damped torsional vibrations of cantilever beam structure. The cross-section of the cantilever is of general shape with torsion bending constant equal to zero. It is with variable dimensions along the length of the beam. The material is assumed to be homogeneous and the coefficients of friction are constant and proportional to I_p

The partial differential equation of dynamic equilibrium is derived by direct consideration of the elastic, inertia and damping torques that act on the infinitesimal line element. The resulting partial differential equation is linear with variable coefficients. The solution is seen into infinite convergent series. Each term of the series is product of eigen functions with respect to time, and space variable along the length of the beam. The eigen function with space is orthogonal and this property is used to isolate the time dependent eigen function.

This solution of the characteristic equation for the time eigen function is solved into close form including the structural friction. For this reason two nonlinear algebraic equations are derived to yield the damping coefficient and damped natural frequency for each mode of vibration. After solving for the time eigen function the general solution is used to derive an expression for the torque at any time and any cross-section.

Finally a particular case of free damped oscillations is considered, in order to demonstrate the estimate of the constants of integration. This is the case of initial torsional deformations at rest.

Key wards: torque, coefficient, friction, deformation, viscous, structural, damping

Introduction

In the theoretical and applied mechanics important place take the free damped oscillations of linear elastic structures. In practice the tendency is to analyse as simple as possible linear structures in order to get an estimate for the dynamical behavior. This dynamical behavior which characterises the structure will further find applications in practice. In this paper are analysed free damped torsional vibrations of a cantilever beam structure with variable cross-section along the length.

Up to now, lot of work has been done in the analysis with constant cross-section along the length, by the normal mode method [2, 3, 4]. But so far, no research is done with variable cross-sec-tion by the normal mode method. Hence, the investigations in this paper represent new research work in this field of applied mechanics.

The analysis is carried out under the action of structural and viscous damping. The structural damping arise from the internal friction of the material. The viscous damping is due to the friction and pressure distribution of the surrounding fluid, air or viscous fluid.

The derived partial differential equation of dynamic equilibrium is solved by making use of orthogonal functions, with respect to the space variable along the length [6]. The results obtained by the analysis are damped natural frequencies of vibration and orthogonal modes of vibrations.

These values are important for forced vibrations, to avoid resonance. The theoretical investi-gations in this paper have great applications in Aeronautical, Civil and Mechanical engineering and corresponding industries.

NOTATION

$[M]$	- mass matrix
$[k]$	- stiffness matrix
A_n	- constant of integration
a_m	- constant
C_n	- constant
c	- coefficient of structural damping
C_v	- coefficient of viscous damping
D_n	- constant

G	- elastic shear modulus
I_p	- second polar moment of inertia
J	- torsional constant
m	- integer index
n	- integer index
i	- integer index
j	- integer index
k	- integer index
l	- cantilever span
x	- space variable
t	- time variable
Q	- twisting torque
T_n	- time function
Y_n	- space function
η	- damping coefficient
ξ	- non dimensional viscous damping coefficient
μ	- structural damping coefficient
θ	- torsional deformation
ω_n	- undamped natural circular frequency
Ω_n	- damped natural circular frequency
λ	- complex constant
ρ	- material density

1.0 THEORETICAL ANALYSIS

The theoretical derivations in this paper for torsional vibrations of the cantilever beam structure will be based on the assumptions made in the field of strength of materials and rigid body mechanics. Therefore we shell go straight into derivation of the partial differential equation of dyna-mic equilibrium of torques. For this reason let us consider the equilibrium of torques that act on a differential element of the structure. The structure is assumed to be of variable cross-sectional dimen-sion along the length. In figure 1 are indicated the toques that act on the infinitesimal element.

Fig. 1 Components of torques acting on the infinitesimal element of the structure

From the theory of strength of materials and rigid body mechanics, the torques indicated in figure 1 are given by the following expressions.

Elastic and structural damping torques are given by:

$$Q = GJ\left(\frac{\partial\theta}{\partial x} + c\frac{\partial^2\theta}{\partial t\partial x}\right)$$

…………………………………………….. a)

Inertia torque due to acceleration is:

$$Q_i = \rho I_\rho \frac{\partial^2\theta}{\partial t^2}dx$$

…………………………………………….. b)

The viscous damping torque is given by:

$$Q_v = C_v \frac{\partial\theta}{\partial t}dx$$

…………………………………………….. c)

Considering the equilibrium of torques acting on the infinitesimal element, the following equation can be written:

$$-Q - Q_i - Q_\upsilon + Q + \frac{\partial Q}{\partial x}dx = 0$$

After clearing the above relation, follows the equation of dynamic equilibrium:

$$-Q_i - Q_\upsilon + \frac{\partial Q}{\partial x}dx = 0$$

……………………………………………… 1)

Substituting the relevant expressions for the indicated members from relation a), b) and

c) into above equation, yields:

$$-\rho I_\rho \frac{\partial^2\theta}{\partial t^2}dx - C_v\frac{\partial\theta}{\partial t}dx + \frac{\partial}{dx}\left[GJ\left(\frac{\partial\theta}{\partial x} + c\frac{\partial^2\theta}{\partial t\partial x}\right)\right]dx = 0$$

After canceling the infinitesimal length dx, the partial differential equation of dynamic equilibrium for torsional vibration is obtained in the form:

$$\rho I_{\rho}\frac{\partial^2\theta}{\partial t^2}+C_{\nu}\frac{\partial\theta}{\partial t}-\frac{\partial}{dx}\left[GJ\left(\frac{\partial\theta}{\partial x}+c\frac{\partial^2\theta}{\partial t\partial x}\right)\right]=0$$

…………………… (2)

The above partial differential equation is linear, with variable coefficients, which will be solved by the normal mode method.

Let us assume that the solution of the above partial differential equation can be given by seri-es of the form:

$$\theta_{(x,t)}=\sum_{n=1}^{n=k}T_{n(t)}Y_{n(x)}$$

……………………………………. (3)

In the above expression $T_{n(t)}$ is eigen function of time variable t only. Its form will be determined from the solution of equation (2). The space function

$$Y_{n(x)}=\sum_{m=1}^{m=k}b_{nm}\sin\left[\frac{(2m-1)\pi x}{2l}\right]$$

……………………………………. (4)

will be recognised as linear combination of the normal functions, solution to the undamped problem of torsional vibration, with constant cross-sectional area along the length. It satisfies the required boundary conditions imposed on it, which are:

$$Y_{n(0)}=0$$

……………………………………………………………… $(4a)$

$$(\frac{dY_n}{dx})_{x=l} = 0$$

…………………………………………………………………… $(4b)$

Also, it represents approximate solution to our case of variable cross-sectioal area, therefore I_p and J, along the length, with or without damping.

To solve for the eigen function $T_{n(t)}$ it is required to obtain exact or approximate values for the undamped natural frequencies of vibration. This paper will be concerned with approximate values for them.

For determining the undamped frequencies Rayleigh - Ritz method will be used $[1,8]$.

The series representation for the solution to the problem of undamped natural frequencies and space functions is of the form (4), i.e.

$$\theta_{(x)} = \sum_{m=1}^{m=k} a_m \sin\left[\frac{(2m-1)\pi x}{2l}\right]$$

……………………………………. (5)

Appling the Rayleigh - Ritz method with this assumption for the mode shape, leads to the standard undamped eigen value and vectors problem:

$$\left(-\omega^2[M]+[k]\right)\{a\}=\{0\}$$

……………………………………. (6)

In the above matrix equation $[M]$ and $[k]$ are symmetric square matrices, and ω and $\{a\}$
are the undamped natural frequencies and modes of vibrations $[5]$. The elements of these matrices are given by the relations:

$$k_{ij} = \frac{(2i-1)(2j-1)\pi^2}{4l^2} G \int_0^l J \cos\left[\frac{(2i-1)\pi}{2l} x\right] \cos\left[\frac{(2j-1)\pi}{2l} x\right] dx$$

…………… . $(7a)$

$$m_{ij} = \rho \int_0^l I_p \sin\left[\frac{(2i-1)\pi}{2l} x\right] \sin\left[\frac{(2j-1)\pi}{2l} x\right] dx$$

.... $(7b)$

The solution of the eigen value problem (6) gives the required undamped natural fre-quencies k and vectors of modes k. Each of these vectors $\{a\}_n$ represent the vector of constants $\{b\}_n$ for the function $Y_{n(x)}$ given by expression (4).

Now, anyone of these functions $Y_{n(x)}$ satisfies approximately the relation:

$$\frac{d}{dx}\left[GJ \frac{dY_n}{dx}\right] \cong -\omega_n^2 Y_{n(x)} \rho I_p$$

.... (8)

The above relation follows directly from the definition of the $Y_{n(x)}$. If the $Y_{n(x)}$ were the exact solution of the undamped problem of vibration, the equal sing must hold in equation (8).

The normal mode function are orthogonal–normal functions with respect to each other, this is:

$$\int_0^l I_p Y_{n(x)} Y_{m(x)} dx = 0 \qquad n \neq m$$

.... (9)

The polar moment of inertia I_p is the weight function. Now, the above important relationship will be proved.

To prove relationship (9) we will consider the product

$$Y_{n(x)} Y_{m(x)} = [b]_n \{\sin \beta_n x\} [\sin \beta_m x] \{b\}_m$$

.... (10)

where:

$[b]_n$ - eigen vector raw

$\{\sin \beta_n x\}$ - colomn of normal functions

$$\beta_n = \frac{(2n-1)\pi}{2l} \qquad n = 1,2,3,............k$$

$\{b\}_m$ - eigen vector colomn

$[\sin \beta_m x]$ - raw of normal function

$$\beta_m = \frac{(2m-1)\pi}{2l} \qquad m = 1,2,3,............k$$

Multiplying equation (10) by I_p and integrating from 0 to l, leads to the following relation:

$$\int_0^l I_p Y_{n(x)} Y_{m(x)} dx = \frac{1}{\rho}[b]_n [M]\{b\}_m$$
……………………………………………….. (11)

In the above expression the matrix $[M]$ is the symmetric mass matrix defined in equation (6).

But from theory of eigen value problem, we know that the eigen vectors of equation (6) are normal to each other, with respect to either $[M]$ or $[k]$ matrices. Hence the relation (11) states that (9) is satisfied. This concludes the proof of orthogonality of normal mode functions one to enather with respect to I_p as a weighting function.

Now, differentiating the assumed solution (3) with respect to t and x, and substituting into equation (2) yields the following equation:

$$\sum_{m=1}^{m=k}\left[\rho I_p T''_{n(t)} Y_{n(x)} + C_v T'_{n(t)} Y_{n(x)} - T_{n(t)} \frac{d}{dx}\left(GJ \frac{dY_{n(x)}}{dx}\right) - cT'_{n(t)} \frac{d}{dx}\left(GJ \frac{dY_{n(x)}}{dx}\right)\right] = 0$$

Making use of relation (8) and assuming that $Y_{n(x)}$ is the exact solution of the undamped case, the above equation can be written in the following form:

$$\sum_{m=1}^{m=k}\left[\rho I_p T''_{n(t)}Y_{n(x)} + C_v T'_{n(t)}Y_{n(x)} + \left(\rho I_p \omega_n^2 T_{n(t)} + c\rho I_p \omega_n^2 T'_{n(t)}\right)Y_{n(x)}\right] = 0$$

.... (12)

Assuming that the coefficient of viscous damping C_v is proportional to the cross-sectional dimension along the length of the cantilever, it is possible to write that:

$$C_v = zI_p$$

....(13)

Substituting the above value for C_v in the equation (12) and rearranging terms yields the following expression:

$$\sum_{n=1}^{n=k}\left[T''_{n(t)} + \frac{z}{\rho}T'_{n(t)} + c\omega_n^2 T'_{n(t)} + \omega_n^2 T_{n(t)}\right]\rho I_p Y_{n(x)} = 0$$

................................(14)

Multiplying the above series by $Y_{m(x)}$, $m = 1,2,3.......n.......k$, and integrating from 0 to l,
using the orthogonality condition (9), isolates the k equations, each one of the form:

$$T''_{n(t)} + \frac{z}{\rho}T'_{n(t)} + c\omega_n^2 T'_{n(t)} + \omega_n^2 T_{n(t)} = 0$$

....(15)

Let us introduce the following substitution:

$$\frac{z}{\rho} = 2\xi\omega_n$$

.... (16)

This means that the z constant takes different value for each mode of vibration. The ξ is other constant.

The coficient of structural friction c is given by the formula:

$$c = \frac{\mu}{\Omega_n}$$
…………………………………………………………………………...(17)

In the above expression the angular frequency Ω_n is the frequency of damped vibration, and
μ is the coefficient of hysteretic damping. With the above expression for c, the differential equa-tion for each $T_{n(t)}$ becoms:

The term in the bracket in the above equation is generated by viscous and structural damping.

The expected solution of equation (18) is damped vibration with respect to the independent variable t. Hence damped harmonic function can be seen as possible solution.

Let us assume that $T_{n(t)}$ can be given by the expression:

$$T_{n(t)} = C_n e^{\lambda_n t}$$
……………………………………………………………………….(19)

In the above expected solution C_n is constant of integration and in original form is complex number. The exponential constant λ_n is also complex number of the form:

$$\lambda_n = -\eta_n + i\Omega_n$$
…………………………………………………………………….(20)

The real part of this complex number is related to the damping of the oscillating motion. The imaginary part of the constant λ_n, Ω_n, is the angular frequency of vibration of the structure, which is in the term in bracket of equation (18).

The estimate of λ_n can be made by obtaining simultaneous solution to two nonlinear algebra-ic equations in η_n and Ω_n. These equations are obtained by equating the real and imaginary part to zero of the complex characteristic function:

$$\lambda_n^2 + 2\xi\omega_n\lambda_n + \mu\frac{\omega_n^2}{\Omega_n}\lambda_n + \omega_n^2 = 0$$

…………………………………………………(21)

After some arithmetic on the above complex number, the two algebraic nonlinear equations are obtained in the following form:

$$-\Omega_n^3 + \Omega_n\eta_n^2 + \Omega_n\eta_n 2\xi\omega_n + \eta_n\mu\omega_n^2 + \Omega_n\omega_n^2 = 0$$

………………………………(22)

$$\Omega_n 2\xi\omega_n + 2\Omega_n\eta_n + \mu\omega_n^2 = 0$$

…………………………………………………(23)

Having obtained the complex number λ_n the general solution for the time dependent function $T_{n(t)}$ as given by the expression (19), in developed form is:

$$T_{n(t)} = e^{-\eta_n t}\left(A_n \cos\Omega_n t + B_n \sin\Omega_n t\right)$$

…………………………………………(24)

The A_n and B_n are real constants of integration and are determined from the boundary con-ditions of the cantilever vibration.

Substituting expression (24) into expression (3) the general solution of the damped free torsional vibrations of the cantilever structure can be written in the form:

$$\theta_{(x,t)} = \sum_{n=1}^{n=k} e^{-\eta_n t}\left(A_n \cos\Omega_n t + B_n \sin\Omega_n t\right)Y_{n(x)}$$

……………………………………..(25)

The above solution is applicable to cantilever structure with cross-sections whose torsion- bending constant is equal to zero.

Now, the expression for torque at any time t and section x will be derived. For this purpose the derivative of the normal modes with respect to x is required. After differentiating $Y_{n(x)}$ w.r.t x yields:

$$\frac{dY_n}{dx} = \sum_{m=1}^{m=k} b_{nm} \frac{(2m-1)\pi}{2l} \cos\left[\frac{(2m-1)\pi}{2l} x\right]$$
……………………………………(26)

Also, the time derivative of $T_{n(t)}$ w.r.t t we obtain:

$$\frac{dT_n}{dt} = e^{-\eta_n t}\left[(\Omega_n B_n - \eta_n A_n)\cos\Omega_n t - (\eta_n B_n + \Omega_n A_n)\sin\Omega_n t\right]$$
……………………(27)

Inserting the relevant expressions from (26) and (27) into (a), the following formula for the torque is obtained:

$$Q_{(x,t)} = GJ \sum_{n=1}^{n=k} e^{-\eta_n t}\left\{\left[A_n\left(1-\mu\frac{\eta_n}{\Omega_n}\right) + \mu B_n\right]\cos\Omega_n t + \left[B_n(1-\mu\frac{\eta_n}{\Omega_n}) - \mu A_n\right]\sin\Omega_n t\right\}\frac{dY_n}{dx}$$

………………………………………………………………………………
(28)

The formula (28) is very slow convergent series. The number k can be very large, depen-ding on the initial boundary condition, cross-section, and of course the precision required. All it states is, that the problem of calculating the torque on a cantilever structure with free end and for free damped vibration is solvable in this manner.

2.0 Numerical Example

An numerical example is presented, in order to show the theoretical investigations given in this paper. The structure to be analysed is shown in figure 2. It is with variable rectangular cross-section, which dimensions vary along the length, as indicated in the figure. The material is steel, with hysteretic damping coefficient $\mu = 0.04$, modulus of elasticity $E = 2.1*10^{11}\ N/m^2$ Poisson's ratio $\nu = 0.3$, damping coefficient $\xi = 0.02$ and material density $\rho = 7850\ kg/m^3$

Fig. 2 Cantilever beam structure with variable cross-sectional dimensions, as shown.

According to the dimensions shown in fig. $2a)$, $b)$, $c)$, the second polar moment of inertia of the cross-section at any section x is given by the formula.

$$I_{p(x)} = 6.6666667 * 10^{-7} * (1 - 0.5x)[0.16 + 0.04(1 - 0.5x)]$$

……………………..(2.1)

The torsion constant $J_{p(x)}$ is given by the expression [7]:

$$J_{p(x)} = 1.066667 * 10^{-7} * (1 - 0.5x)^3 [1 - 0.315(1 - 0.5x)]$$

…………………………….(2.2)

The cantilever is initially at rest, so that its initial velocity is zero, and initial displacement

$\theta_{0(x,t=0)}$ given by the expression

$$\theta_{0(x,t=0)} = \theta_0 \left(\frac{x}{l} \right)$$

…………………………………………………………….....   (2.3)

From expression (27), since the velocity at time $t = 0$ is zero, follows that:

$$B_n = \left(\frac{\eta_n}{\Omega_n} \right) A_n$$

……………………………………………………………….. (2.4)

Therefore the response for $\theta_{(x,t)}$ will be given from formula (25) in the form:

$$\theta_{(x,t)} = \sum_{n=1}^{n=k} e^{-\eta_n t} A_n \left(\cos\Omega_n t + \frac{\eta_n}{\Omega_n} \sin\Omega_n t \right) Y_{n(x)}$$

.... (2.5)

Now remains to determine the constants A_n. This will be done by equating (2.3) and (2.5) for $t = 0$. Therefore it follows that:

$$\theta_0 \frac{x}{l} = \sum_{n=1}^{n=k} A_n Y_{n(x)}$$

.... (2.6)

Multiplying relation (2.6) by $I_{p(x)} Y_{n(x)}$ and integrating from 0 to l yields:

$$A_n = \frac{\theta_0}{l} \int_0^l x I_{p(x)} Y_{n(x)} dx \frac{1}{\Phi_n}$$

.... $(2.7a)$

Where Φ_n is given by the expression:

$$\Phi_n = \int_0^l I_{p(x)} Y_{p(x)}^2 dx$$

.... $(2.7b)$

For any particular section $x = r$, the solution (2.5) can be written as:

$$\theta_{(x=r,t)} = \sum_{n=1}^{n=k} T_{n(t)} D_{(x=r)}$$

.... (2.8)

For the cantilever shown in figure 2, for $x = r = l$ the following values for

η_n, Ω_n, D_n, $n = 1,2,3........10$ are obtained and tabulated in table 1.

TABLE I

Numerical results for relevant response values

n	η_n 1/sec	Ω_n rad/sec	D_n / θ_0
1	-2101.311	53469.827	0.000964
2	-2502.922	62498.052	0.000170
3	-1817.959	45394.500	0.001139
4	-1564.974	39067.845	0.003648
5	-154.974	3869.718	0.924878
6	-373.583	9328.373	-0.008691
7	-607.675	15171.162	0.037934
8	-1083.201	27047.581	0.009759
9	-1322.721	33028.385	0.003117
10	-844.922	21097.726	0.006125

3.0 CONCLUSION

From the theoretical investigation in this paper it is possible to draw the following conclusions.
Firstly, for the torsional vibrations of a cantilever beam structure it can be concluded that the
modal function are normal to each other with weight function I_p. This statement was proved in the analysis. Secondly, the modeling of the viscous damping coefficient, equation (16), together with the two nonlinear algebraic equation (22), and (23) is physicly correct. Namly it allows calculation of almost constant modal damping parameter for each idependent mode of vibration.

These two conclusions bring the new theoretical achievements in this paper.

Резиме

Во овој труд се анализирани слободни придушени торзиони вибрации на конзол-на конструкција. Попречниот пресек на конзолната конструкција е сосема произволен, со торзиона-свиткувачка константа еднаква на нула. Тој е со променливи димензии долж распонот на конзолата. Материјалот од кој е направена конструкцијата е хомоген.

Изведена е парцијална диференцијана равенка на динамичка рамнотежа со директно разгледување на еластичниот, инерцијалниот и придушувачките спрегови кои дејствуваат на бесконечно мал елемент. Така изведената диференцијална равенка е линеар-на со променливи коефициенти. Нејзиното решение е претпоставено со конвергентен ред. Секој член на овој ред претставува производ на сопствени функции од време и простор.

Карактеристичната равенка на сопствената функција по време е решена во затворена форма, вклучувајки го и конструктивното придушување.Така да изведени се две нелинеар-ни алгебарски равенки, чие решение ги дава коефициентот на придушување и кружната придушна фрекфренција, за секоја форма на осцилирање. Добиеното општо решение е употребено да се изведе израз за торзиониот спрег во било кое време и било кој пресек.

На крајот е разгледуван посебен случај од интерест на слободни придушни осцилации, со цел да се демострира одредувањето на константите на интеграција. Ова е (сторено) направено за случајот на конзола со почетни деформации во мирување.

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TABLE I - Dr. Mile R. Mihajlov

Numerical results for relevant response values

n	η_n 1/sec	$\Omega_n rad/\sec$	D_n/θ_0
1	-2101.311	53469.827	0.000964
2	-2502.922	62498.052	0.000170
3	-1817.959	45394.500	0.001139
4	-1564.974	39067.845	0.003648
5	-154.974	3869.718	0.924878
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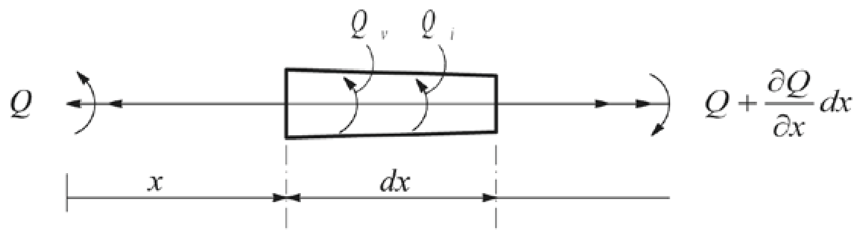
10	-844.922	21097.726	0.006125

Dr. Mile R. Mihajlov
Potpis na slikite

Fig. 1 Components of torques acting on the
Infinitesimal element of the structure

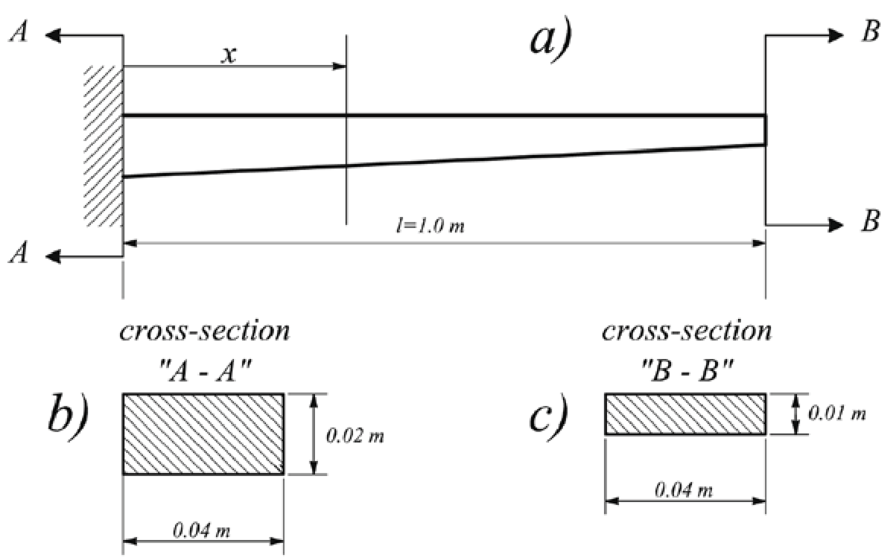
Fig. 2 Cantilever beam structure with variable
cross-sectional dimension, as shown

Dr. Mile R. Mihajlov



Q_v
Q_i
Q
$Q + \frac{\partial Q}{\partial x} dx$
x
dx

Fig. 1



A
a)
B
x
l=1.0 m
cross-section
"A - A"
b)
0.02 m
0.04 m
cross-section
"B - B"
c)
0.01 m
0.04 m

Fig. 2

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