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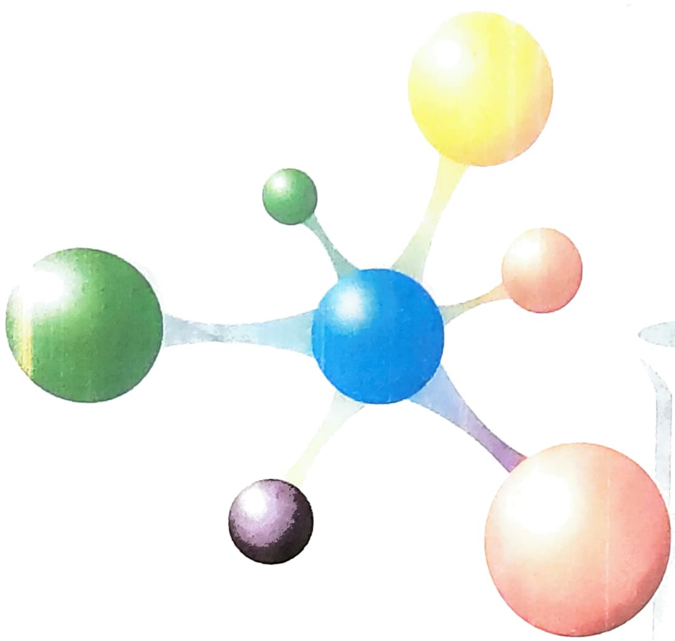

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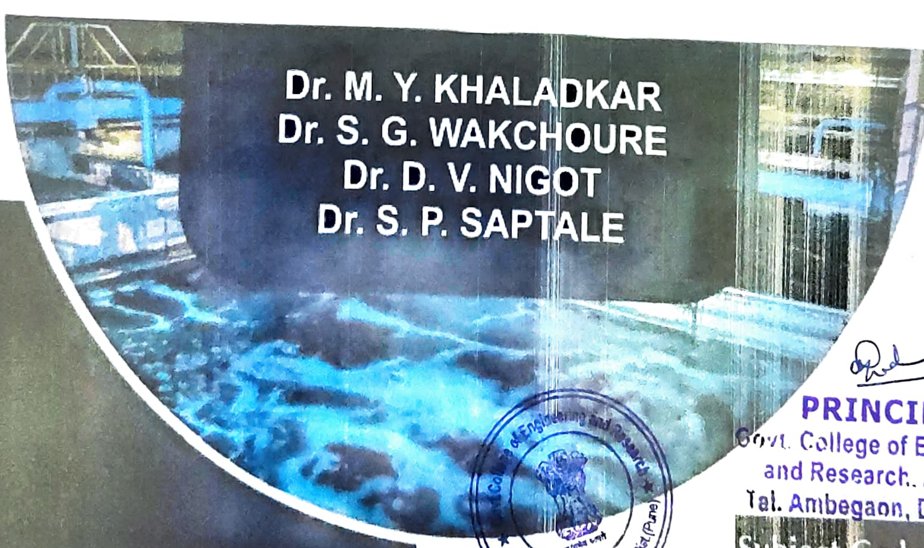

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S. N. Merchant
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Advances in Signal and Data Processing

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Preface

The present era of technological advancements is moving at a very fast pace. It is therefore essential to keep oneself abreast with all the recent developments in various engineering domains. The book discusses various state–of–the-art developments in the diverse area of communications, data processing and signal processing, and the endeavor has been to bring together some of these developments in a concise platform that would benefit students, researchers, academicians and industry people. The chapters presented in the book have been selected on the basis of relevance and mathematical deliberations on the topics. Apart from the above-listed domains, this book has additionally included topics on social issues providing advanced technological solutions.

Chapter "Deep Semantic Segmentation for Self-driving Cars" introduces the technique of semantic segmentation of urban scene for a self-driving car that comprises three sub-systems in navigation, viz. lane finding, urban scene understanding and geo-positioning. In Chapter "Shot Boundary Detection Using Artificial Neural Network," hybrid video shot boundary detection process using feature extraction by mean log difference is discussed in combination with artificial neural network techniques. A system for leaf parameter analysis is proposed in Chapter "Custard Apple Leaf Parameter Analysis, Leaf Diseases, and Nutritional Deficiencies Detection Using Machine Learning," where detection of N, P and K deficiencies and leaf diseases is accomplished using K-nearest neighbors (k-NN) and support vector machine (SVM) algorithms. A typical problem of recognizing and removing the rain streaks on photographs by an improved convolutional neural network (CNN) architecture is discussed in Chapter "Single Image Rain Removal Using Convolutional Neural Network." A study of voice samples for two disorders—hypo and hyper—along with normal voice samples is considered in Chapter "A Robust Approach of Estimating Voice Disorder Due to Thyroid Disease" to create a databank for three classes—normal, hypo and hyper. A combined classifier, i.e., SVM and HMM (hidden Markov model), was utilized.

In Chapter "Face Recognition Using Golden Ratio for Door Access Control System," a combination of Viola–Jones face detection method with characteristics of extracting golden ratio is discussed to improve the security of sensitive places through facial recognition. This book has included chapters on topics such as underwater detection of objects, adaptive background subtraction models for shot detection, acoustic classification and evaluation of bird species using support vector machine and artificial neural networks. In Chapter "Feature-Based Model for Landslide Prediction Using Remote Sensing and Digital Elevation Data," a study to generate landslide susceptible maps and landslide hazard zonation maps is presented using the digital elevation model for the prediction of future landslides. Chapter "Emotion Recognition using Gamma Correction Technique Applied to HOG and LBP Features" discusses techniques on emotion recognition using gamma correction when applied to histogram of oriented gradient (HOG) and LBP features. The book also includes diverse areas on images and speech signal processing, besides the above-mentioned topics such as analysis of vocal tract parameters of speech, 3D reconstruction of plant features with non-destructive plant growth monitoring systems, digital image watermarking by fusion of wavelet and curvelet transform, and content-based image retrieval (CBIR) techniques.

This book also features many recent advancements on machine learning algorithms. Chapter "Automatic Gear Sorting Using Wireless PLC Based on Computer Vision" discusses conversion of wired PLC into wireless PLC by interfacing the PLC with the Wi-Fi module to enable real-time surveillance and control of the system of equipment sorting via Wi-Fi module interfacing with PLC. Chapter "Machine Learning Feature Selection in Archery Performance" discusses machine learning feature selection in Archery performance using Boruta algorithm, Chapter "Skin Lesion Classification Using Deep Learning" deliberates on skin lesion classification using deep learning, Chapter "Deep Learning-Based Paperless Attendance Monitoring System" deals with deep learning-based paperless attendance monitoring system, and Chapter "Image Analytics to Detect Cigarette in an Image Using Deep Learning" deals with image analytics to detect cigarette in an image using deep learning.

In the domain of antenna design and communication, Chapter "Frequency and Pattern Reconfigurable Antenna for WLAN and WiMAX Application" proposes an innovative bow tie frequency and pattern reconfigurable antenna for WLAN and WiMAX applications. Chapter "Design of a Power Efficient Multiband Patch Antenna" gives a design consideration of multiband patch antenna. Chapter "A Frequency Reconfigurable Antenna for Sub-GHz and TV White Space Applications" discusses a frequency reconfigurable antenna for sub-GHz and TV white space. Chapter "Comparative Analysis of Least Squares Method and Extended Kalman Filter for Position Estimation in GPS Receiver" provides a comparative analysis of position estimation techniques in a GPS receiver by using the least squares (LS) method and extended Kalman filter method (EKF). Fair scheduling non-orthogonal random access for 5G networks is presented in Chapter "Fair Scheduling Non-orthogonal Random Access for 5G Networks." Chapter "An Improved Carrier Frequency Offset Estimation Under Narrowband Interference in OFDM Cognitive Radio" surveys various techniques to estimate carrier frequency offset (CFO) for OFDM cognitive radio.

This book has also included few interesting power-related chapters. Chapter "Trends in Energy Management System for Smart Microgrid—An Overview" reviews several energy management systems developed based on different strategic approaches available for microgrid on demand-side management. Chapter "Discontinuous PWM Techniques to Eliminate Over-Charging Effects in Four-Level Five-Phase Induction Machine Drives" presents equivalent circuit modeling of a Li-ion battery cell and its state of charge estimation using the Kalman filter algorithm in MATLAB Simulink. A Transition Based Odd/Full Invert (TBO/FI) coding scheme, which focuses on crosstalk avoidance and low dynamic power consumption in NoC links, is also discussed. Chapter "Efficient Design of Drone Flight Control Using Delay Tolerant Algorithm" presents a study to reduce the human error parameter in the probable causes for drone crashes.

Various social issues are also presented by authors with their technical solutions. In Chapter "IRIS: An Application for the Visually Impaired Using Google Cloud API," the authors present the design considerations of a cost-effective and efficient visual aid which proposes a smart stick (IRIS) to help the user in obstacle detection and navigation. Chapter "Implementation of Hand Gesture Recognition System to Aid Deaf-Dumb People" considers a time system for hand gesture recognition that acknowledges hand gestures and then converts them into text and voice. Statistical validity of pre-smoking and post-smoking impact on heart rate variability among middle-age men is presented in Chapter "Statistical Validity of Presmoking and Postsmoking Impact on Heart Rate Variability Among Middle Age Men." Chapter "Analysis of Chronic Joint Pain Using Soft Computing Techniques" analyzes the chronic joint pain remedies using soft computing techniques.

A critical evaluation of each submitted chapter by at least two expert reviewers was carried out. The authors re-submitted with all suggested alterations given by the expert panel. The book would definitely be of immense help to passionate researchers, students and industry persons.

Mumbai, India S. N. Merchant
Pune, India Debashis Adhikari
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Contents

About the Editors

Dr. S. N. Merchant is currently a Professor (Emeritus Fellow) in the Department of Electrical Engineering at IIT, Mumbai. He obtained his BTech, MTech and PhD degrees from the department of Electrical Engineering, IIT Mumbai. His broad area of research interest are wireless communication, wireless sensor network, signal processing, multimedia communication and image processing. His noteworthy contribution has been in solving state of the art signal and image processing problems faced by the Indian Defense forces. He serves on the editorial board of two international journals: International Journal of Ultra-Wideband Communication & Systems and International Journal of Distributed Sensor Networks. He is a fellow of Institution of Electronics and Telecommunication Engineers, IETE and is a recipient of 10th IETE Prof SVC Aiya Memorial Award for his contribution in the field of detection and tracking. He is also the recipient of the 9th IETE Prof SVC Aiya Memorial Award for "Excellence in Telecom Education". He is the winner of 2013 VASVIK Award in the category of Electrical & Electronic Sciences and Technology.

Dr. Krishna Warhade is currently the Dean Research, Development, Innovation and Consultancy and Professor and Head of the Department, department of Information Technology at MIT College of Engineering and Dr. Vishwanath Karad MIT World Peace University, Pune, India. He has obtained his BE (Electronics) and ME (Instrumentation) from Shri Guru Gobind Singhji Institute of Engg. & Tech., Nanded, under Swami Ramanand Teerth Marathwada University, Nanded. He obtained his PhD from IIT, Mumbai. His research interests include healthcare, video segmentation, wavelets, digital signal processing, digital Image processing, digital filter design and ICT in agriculture. He has worked on various collaborative projects with Bhaba Atomic Research Center (BARC), Blackberry and Konkan Railway Corporation Limited (KRCL).

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An Algorithm for Skew Angle Estimation and It's Application Domain

Unnati Raju Kulkarni, Hemant Goraksh Ghuge, Revati Anand Kulkarni, and Kirti Vasant Thakur

Abstract Angle detection and estimation is important in various fields like line following mobile robots, document analysis, construction sites etc. There are several methods and algorithms proposed earlier to do that. This paper represents a new algorithm to estimate skew angle and its possible applications in different fields. In this algorithm, angle in the preprocessed black-white image is estimated using matrix traversal and slope equation from Euclidean geometry. This algorithm can measure the angle between −90° and +90° efficiently.

Keywords Algorithm · Image processing · Skew angle estimation · Multi-domain application

1 Introduction

Nowadays, digital image processing [1] is flourishing in numerous domains like medical, forensics, defense, robotics, construction works, document processing, space imaging, etc. The basic methods of digital image processing in the medical field are image restoration and image enhancement [2]. Forensic imaging processing uses a variety of computer techniques which involve digital filters that can suppress noise and sharpens the image. However, in satellite interpretations, statistical methods are applied to the digital images and after processing the various discrete surfaces are

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identified by analyzing the pixel values [3]. In robotics, image processing is used for navigation, marker detection, angle estimation. Along with this, it can also be used at construction sites for the accurate designing of bridges or for observing the cracks on walls [4]. The essential steps in document analysis are skew detection and correction. Recognition of character begins with data acquisition and ends up with a skew correction method. Currently, there are many skew angle estimation algorithms using image processing which requires connected component analysis and restricted for document analysis. The purpose of this paper is to introduce a new algorithm for skew angle estimation and it's probable application area.

2 Literature Survey

In recent years, many research works were performed for angle estimation using image processing techniques that can be used for line navigation [5], document analysis [6–8], construction sites. However, there are some uncertain issues despite that fact the technology in this field is mature. Hough transform is utilized to identify straight lines in an image. The peak in the Hough space represents the dominant line and its skew. The real downside of this method is that it is computationally expensive and is very challenging to get a peak in the Hough transform when text becomes sparse. The skew angle is the angle made with the normal or perpendicular. Various techniques have recently been proposed for recognizing document image skew angles. Chaudhuri and Chaudhuri [9] propose a precise technique based on the cross-correlation of vertical image slices They exhibit their strategy on both English and Bengali languages, however for huge regions of graphics or pictures the method will fail. The method most frequently utilized is the projection profile method proposed by Baird [10], however, this is only reliable for skew angles within ±15°. Postl's method [11] is accurate but requires computationally complex integration involving trigonometric functions. It is not clear whether this method is insensitive to graphics in the image. Smith [12] proposed a method of fitting connected components into row bins, updating the vertical shift across the image. This is again precise but has only been tested for angles up to 26.8°. Yu and Jain [13] have developed a very accurate method using the Hough transform of the centroids of connected components.

However, for the applications other than document analysis, skew angle measurement techniques are not yet tested. Wei et al. [14] proposed an algorithm for Lane detection and tracking based on hough transform. In this they controlled the slope of lane lines in two different frames and searched for corner pixel. They claimed for fast operation speed, high accuracy and good robustness but it cannot completely avoid the interference of other lines in the identification.

Thus, applications such as document analysis, navigation, bridges and home construction, posture detection have an emerging area of research and recognizing which is one of the focus of the present work. Generally, real-world situations that involve different angle measurements is in construction work. The roof of a house has to be at least 39° and at max 48° to anticipate downpour water, otherwise the water leaks inside the house. Using skew angle algorithm, angle of the roof can be calculated, also during navigation of a vision based wheeled robot the angle of a line can be detected. Using the proposed algorithm of skew angle estimation the posture of the human body can also be detected. This helps in medical awareness. Thus skew angle estimation and its applications are the area of focus of this paper.

3 Algorithm

The proposed algorithm is related to the skew angle estimation. The algorithm accepts only preprocessed black and white image with extracted region of interest.

Step 1: Original image acquisition.

Step 2: Preprocessing of image(extracting region of interest, converting to BW image). The image preprocessing includes minimizing of noise in the image and extracting the region of interest. User should perform preprocessing according to his/her requirement.

Step 3: There are two methods for vertical and horizontal traversing of matrix of BW image. For convenience they are labelled as method X and method Y. Here, the transition of pixel values from 0 to 1 is observed. In method X, traversing of matrix is row wise from left to right, whereas in method Y, traversing is from top to bottom column wise. The Pixel location of transition is stored in matrix I_{trans}.

$$I_{\text{trans}} = [\,]_{(\text{row}*2)} \ldots \text{method}X \tag{1}$$

$$I_{\text{trans}} = [\,]_{(\text{col}*2)} \ldots \text{method}Y \tag{2}$$

Each row of I_{trans} contains x and y coordinates of transition for that row or column according to the respective method.

Step 4: If no transition is found for a row or column, by default -1 is given for x and y coordinates.

Step 5: Now minimum and maximum positive values of column 1 of I_{trans} are found out and difference is calculated.

$$\text{delta}_x = \max(I_{\text{trans}}(:, 1)) - \min(I_{\text{trans}}(:, 1)) \ldots \text{method}X \tag{3}$$

$$\text{delta}_y = \max(I_{\text{trans}}(:, 2)) - \min(I_{\text{trans}}(:, 2)) \ldots \text{method}Y \tag{4}$$

Step 6: Comparing $delta_x$ and $delta_y$, $y_{\min}$, $y_{\max}$ or $x_{\min}$ and $x_{\max}$ are deducted from I_{trans} matrix of respective method. Points $x_{\min}$, $x_{\max}$, $y_{\min}$ and $y_{\max}$ represent end points of a line.
Step 7: The slope of this line can be calculated as

$$m = \frac{y_{\max} - y_{\min}}{x_{\max} - x_{\min}} \tag{5}$$

Step 8: By using trigonometric formula for tangent of difference between two angles,

$$\tan(\theta_1 - \theta_2) = \frac{\tan(\theta_1) - \tan(\theta_2)}{1 - \tan(\theta_1) * \tan(\theta_2)} \tag{6}$$

slope between two lines is calculated.

Step 9: A virtual straight line is considered as a reference and the angle is calculated w.r.t. to that line. Thus,

$$\tan(\theta_1) = \tan(0) = 0 \tag{7}$$

Required angle,

$$\theta_2 = -\tan^{-1}(m). \tag{8}$$

4 Flowchart

See Fig. 1

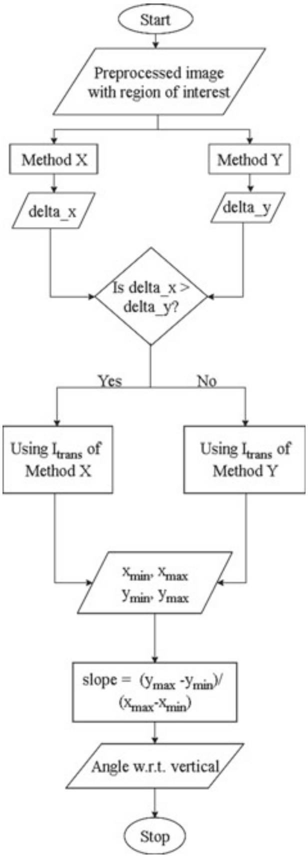

Fig. 1 Flowchart for proposed skew angle estimation algorithm

5 Experimental Analysis

Proposed algorithm is tested for various applications such as line following systems, construction area, document analysis, posture analysis, etc. Figure 2 shows the images for proposed applications on which the skew angle estimation algorithm is tested.

Figure 2a shows the scanned document image as one of the skew angle estimation domain. Nowadays, text recognition using OCR is being more popular. The proposed algorithm can be used for detection and correction of skew angle which ultimately leads to improve the accuracy of OCR. Figure 2b [15] depicts a person who tends to slouch which results in improper posture. It can be harmful to the human body if it happens repeatedly. The proposed algorithm can be used for the detection of bending positions and it is easy to integrate with various software that can notify the person to correct his posture.

(a) Scanned Document Image

(b) Person's Posture [15]

(c) MiniDrone Environment

(d) House

Fig. 2 Images for proposed applications

Figure 2c portrays minidrone environment mainly consists of the line following including various angles for navigation of the drone from one point to another. The line can be followed by various environments and hardware and their time complexity and accuracy is based on the same. According to the survey, MATLAB has its algorithm for detection of the angle between two intersecting lines but it lacks in single line skew estimation. This algorithm is also can be used for vision-based path navigation for mobile robotics.

Figure 2d shows the house having roof at a particular angle. The proposed algorithm can be used in the construction domain for the roof angle measurement. This is accurate and more time saving than current methods.

Figures 3, 4, 5 and 6 represent how the algorithm deducts respective angle. From three images of each application, the first one is an image containing region of

(a) Resize Image (b) BW + Angle (c) Corrected Image

Fig. 3 Document analysis of Fig. 2a

(a) Cropped Image (b) BW Image (c) Angle

Fig. 4 Person's posture of Fig. 2b

(a) Camera's Image (b) BW Image (c) Angle

Fig. 5 MiniDrone camera's image of Fig. 2c

(a) Cropped Image (b) BW (c) Angle

Fig. 6 House image of Fig. 2d

interest, the second one is the image after preprocessing and binarization whereas third image is the output image with required angle. Thus, this algorithm can be successfully used for angle estimation in video processing, posture angle estimation and skew angle estimation.

6 Conclusion

Proposed skew angle measurement algorithm is verified with suggested fields and it satisfied the basic requirement of angle estimation. Earlier, skew angle estimation [6–13] has been restricted to the document analysis. This paper suggest diverse applications areas of skew angle estimation.

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Theory and Practice in Earthquake Engineering and Technology

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Preface

The editors are pleased to present this text to the readers on theory and practice in earthquake engineering and technology. Extensive research work is conducted on earthquake engineering and allied areas across the world, quite naturally because of its relevance to the life safety of people. In the present text, the authors have provided a broad spectrum of research works carried out under several disciplines and sub-disciplines of earthquake engineering and technology, from theory to practice, starting from the rudiments thereof. Matsagar (2022) has initiated the discussion on earthquake engineering and technology by setting the tone of the deliberations within this text. Under the overarching umbrella of earthquake engineering and technology, systematic categorization of various disciplines and sub-disciplines has been made, while introducing them, some ongoing research works have also been presented in this opening chapter. The subsequent chapters cover several aspects of geology, seismo-tectonics, regional seismology, geotechnical earthquake engineering, soil-structure interaction, structural engineering, and dynamic response control of structures.

Application of site response studies in seismic hazard microzonation and ground characterization has been presented by Shukla (2022) in the next chapter. In engineering seismology, site response study helps in modeling the effects of the near surface layers of soil on earthquake ground motions, which is an important requirement in seismic hazard microzonation. Ground response studies carried out world over have been reviewed herein, and the discussion is then made in the Indian context.

Ravi-Kiran and Jakka (2022) have presented seismic design of shallow foundations giving the conceptual principles and design methodologies. They have as well deliberated on the current Indian practices, in the framework of codes. Foundation design for structures that are resilient under seismic activities poses several challenges to a geotechnical earthquake engineer owing to the complexities involved in the dynamic soil-structure interaction (SSI) problems. A geotechnical engineer is required to design foundation addressing all such complexities and yet provide design adequately safe under the anticipated forces. Such design procedure for shallow foundations, in particular, has been dealt with in this chapter.

During an earthquake event, adjacent structures may collide with each other, which is called seismic pounding, generating high impact forces in the structural members. Such seismic-induced pounding of structures and its mitigation through some connecting links have been proposed by Dey Ghosh and Aviral Kumar (2022). The authors have recommended to relook the current provisions of maintaining adequate gap between adjacent buildings and bridge girder in order to preclude possibility of seismic pounding, else connecting links in the form of energy absorbing dampers have been recommended.

Soil-Structure Interaction (SSI) plays a crucial role in evaluating seismic response of structures, which cannot be overlooked, especially when the underlying soil is flexible. The influence of the nonlinear SSI on yielding of pile embedded in stratified soil has been discussed in detail by Bhattacharjee and Borthakur (2022). Estimating yield moment of a pile embedded in stratified soil by conducting static pushover analysis has been shown in this chapter by modeling the pile-soil system in the open source simulation tool, OpenSees.

When soil loses its shear strength under the earthquake-induced dynamic excitation due to increased pore water pressure soil liquefaction is considered to have occurred. Satyam and Priyadarsini (2022) have fittingly discussed development of liquefaction susceptibility maps for Vishakhapatnam City in India that would be useful in the infrastructure development projects in future. The hazard maps developed based on the liquefaction severity and potential indexes are projected to help solving engineering problems in the considered study area.

Several earthquake response modification and control techniques and devices have been invented of late. One among such dynamic response control methods is seismic base isolation of structures. Base isolation systems are also proven effective for seismic response control of masonry dome (Kakade et al., 2022). The authors have adequately shown the effectiveness of the base isolation system employed in dynamic response control of masonry dome when subjected to earthquake base excitation. Especially, development of tensile stresses in the masonry dome has shown to be reduced advantageously.

With new developments in knowledge and knowhow, rapid changes are being made in the codes and standards. Such changes mandate reassessment of structures on new scale, parameters, or norms, and subsequently adopting measures to make them code compliant. Sarmah et al. (2022) have presented a method for rapid retrofitting of reinforced concrete (RC) columns using iron-based shape memory alloy, Fe-SMA to achieve enhanced seismic performance. This new technique helps in seismic retrofitting of RC columns by winding of thermally prestressed and actively controlled, Fe-SMA strips around the columns.

Considerable research contributions have been made at the Indian Institute of Technology (IIT) Roorkee in developing earthquake early warning system. Relevance of earthquake early warning system in India has been deliberated by Ashok-Kumar et al. (2022), especially emphasizing the need for addressing the blind zone region within 100 km radius from the epicenter. Nonetheless, research efforts are further required to be taken in making the earthquake early warning system more reliable and advancing/increasing the time for making the prediction, even in the near source regions. Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL), and Neural Network (NN) techniques are finding their enormous applications in the earthquake early warning system to this effect, after such a pilot project has been completed at IIT Roorkee.

Local authorities require guidance on city planning, earthquake risk mitigation, and response actions taken after occurrence of an earthquake. After an occurrence of unfortunate earthquake estimating the loss incurred is also required, which is a daunting task. How to carry out such estimation of losses has been presented by Meslem et al. (2022), who have taken an example on earthquake loss information system developed for the North-Eastern City of Guwahati, Capital of Assam in India. The procedure laid down in this chapter can suitably be applied for a city before/after occurrences of earthquake.

Occurrence of earthquakes is unpredictable in terms of time and intensity in different regions. However, for important mega-projects, such as river-valley projects, estimation of probable intensity of earthquakes at the proposed site or location is quite essential. To this effect, a Probabilistic Seismic Hazard Analysis (PSHA) for hydropower project sites in the Himalayan Region has been carried out and presented by Srivastav and Satyam (2022) in their chapter. With an aim to quantify the rate of exceeding certain specified earthquake ground motion level at a specific project site, the PSHA technique has been employed for three chosen hydropower project sites located in Uttarakhand, Himachal Pradesh, and Jammu and Kashmir in India, which will be helpful in generating a site-specific seismic hazard map.

In heavy industries and structures, the structure-equipment-piping interactions are important considerations under the earthquake excitation (Reddy, 2022). Failures are likely to occur not only in the parent (host) structure but also either in equipment or in the piping systems, which sometimes are categorized as lifeline structures. The forces induced in the structure, equipment, and piping depend upon how they are interacting with each other. It is notable that such dynamic interactions vary largely based on whether the secondary structures are acceleration-sensitive or displacement-sensitive. Thereby, seismic designs of the primary and secondary structures are greatly influenced by the structure-equipment-piping interactions, as discussed in this chapter.

Advanced seismic design approaches are being adopted in modern design codes and standards. In this context, the Performance-Based Seismic Design (PBSD) of Reinforced Concrete (RC) structures discussed by Gwalani and Singh (2022) becomes highly relevant. In the near future, the Bureau of Indian Standards (BIS) is anticipated to publish standard guidelines on the PBSD of code-compliant reinforced concrete buildings. Hence, this chapter, describing the concept of the PBSD and how to apply it in earthquake-resistant design of buildings, appropriately illustrating the Nonlinear Static Analysis (NSA) and Nonlinear Time History Analysis (NLTHA) methods, is very timely and useful to the structural designers.

Borah et al. (2022) have carried out a comparative analysis of the Standard Spectral Ratio (SSR) and Horizontal to Vertical Spectral Ratio (HVSR) methods for site response analysis. They have concluded that the SSR method provides a more accurate and conservative estimate of site amplification response as compared to the HVSR, which therefore can suitably be adopted for the seismically active North-Eastern Regions in India.

It is indeed pleasing to see that a wide variety of topics have been dealt with in these chapters of the book. We feel that these contributed chapters in this book have elaboratively highlighted tenets of theory and practice in earthquake engineering and technology aptly. Therefore, we believe that the latest developments in earthquake engineering and allied disciplines presented through these 14 chapters will prove to be highly informative to the readers and pave ways for further research.

Guwahati, India
Mangalore, India
Roorkee, India
Hauz Khas, India

T. G. Sitharam
Sreevalsa Kolathayar
Ravi S. Jakka
Vasant Matsagar

Contents

Experimental Study of Closed-Loop Thermosyphon System Using Different Working Fluids

Mahasidha R. Birajdar and C. M. Sewatkar

Abstract Thermosyphon is a heat transferring device which transfers heat over long distance and where the liquid is returned to the evaporator by gravitational force. The closed-loop thermosyphon (CLT) transfers heat with phase change phenomenon. A large amount of heat is transferred from evaporator section to condenser section with a relatively small temperature difference. The thermal performance of closed-loop thermosyphon (CLT) is influenced by the governing parameters like filling ratio, heat input, adiabatic length, working fluids, etc. This paper investigates the effects of these parameters on thermal performance of closed-loop thermosyphon system for different working fluids. In this work the filling ratio (FR) is varied in the range of 30–80% in the step of 10% at various heat inputs of 0.5–2 kW with a step of 0.5 kW for each evaporator and adiabatic length (vapor line length) is taken as 200 mm. The working fluid used as methanol, ethanol, acetone, and distilled water. The performance plots of the performance parameters like thermal resistance, evaporative heat transfer coefficient (HTC), and condenser heat transfer coefficient for these different working fluids, heat inputs, and filling ratios are plotted and results are analyzed. From the result, it is found that acetone has comparatively lowest thermal resistance. Water has comparatively highest evaporative heat transfer coefficient as well as condenser heat transfer coefficient.

Keywords Closed-loop thermosyphon · Thermal performance · Working fluid

1 Introduction

Closed-loop thermosyphon (CLT) transfers huge amounts of heat from evaporator region to condenser region with a relatively small temperature difference. Heat applied at evaporative section converts liquid into vapor and the vapor then condenses after passing through the condenser section. During this process, heat is transferred from evaporator to condenser through latent heat of evaporation, therefore this method is very efficient than conventional heat exchange method. In this process of

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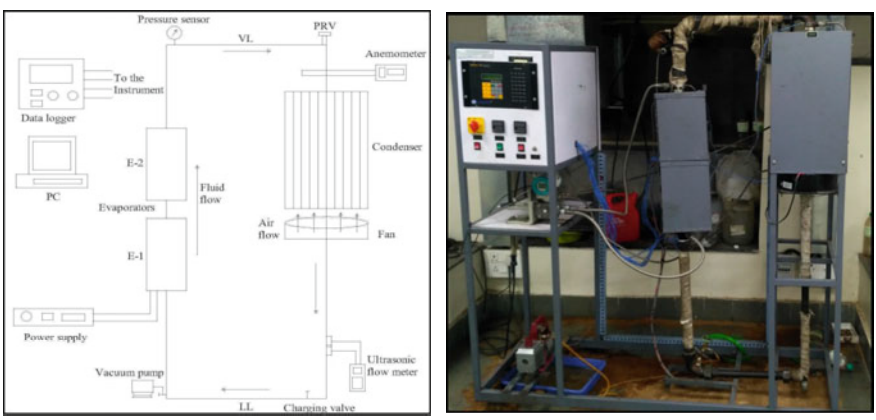
heat transfer, there is no requirement of power or pump for transferring heat from one location to another. Therefore, this method of heat exchange is known as passive heat exchange method [1–3]. Analysis of closed-loop thermosyphon (CLT) is carried out by different researchers using different working fluids. Pal et al. analyzed two-phase compact thermosyphon which is applied to the cooling process of computers. The thermosyphon experimented using the working fluids like PF5060 (dielectric liquid) and deionized water at different heat inputs such as 20–90 W. They noticed that performance of thermosyphon is affected by the working fluids and found that water is better working fluid than PF5060 [4]. Ersoz and Yıldız reported the effect of working fluids such as distilled water, methanol, and petroleum ether on thermoeconomic analysis of two-phase closed thermosyphon (TPCT). For all input conditions, the maximum energy efficiency and exergy efficiency are obtained for methanol whereas the minimum energy and exergy efficiency is obtained for petroleum ether. Also, they conclude that distilled water is more effective working fluid than methanol and petroleum ether in terms of cost [5]. Jouhara and Robinson carried out an experimental study of two-phase closed thermosyphon (TPCT) with working fluids such as distilled water and dielectric heat transfer fluids such as FC-77, FC-3283, and FC-84. They noticed that the distilled water filled thermosyphon shows better thermal performance than other working fluids [6]. Karthikeyan et al. carried out experiments on the two-phase closed thermosyphon (TPCT) charged with distilled water and *n*-butanol solution. The thermal performance of an aqueous solution of *n*-butanol charged TPCT was better than the distilled water [7]. Tong et al. reported the thermal performance of two-phase closed-loop thermosyphon charged with R744 and R22. They noticed that R744 filled two-phase closed-loop thermosyphon may work with a very small temperature difference of 5 °C. Also, they conclude that the thermal performance of working fluid R744 is better than the fluid R22 [8].

From the literature review, it is noticed that at the lower operating temperatures, working fluid water shows less satisfactory thermal performance compared to the low saturation temperature fluids. Also, at lower heat input water has its limited application. Therefore, in the present study, comparative performance of closed loop thermosyphon (CLT) using different working fluids such as ethanol, methanol, acetone, and water is reported as a function of different governing parameters such as heat input, filling ratio, and adiabatic length (vapor line length) [9].

2 Experimental Setup and Procedure

The thermosyphon test rig consists of a closed-loop with two evaporators with two heaters, a plate-type condenser, a cooling (fan) section, a liquid reservoir for charging, a vacuum pump, data acquisition (logger) system, and measuring instruments like ultrasonic flow meter, anemometer, pressure transmitter, and thermocouples. The lower portion of closed loop thermosyphon (CLT) is having a vacuum seal valve for the connection of thermosyphon to vacuum pump and a charging valve for the connection of the working fluid to the thermosyphon tube. The mechanical vacuum pump is used for evacuation of closed-loop and also for removal of non-condensable gases from the thermosyphon. The closed loop thermosyphon (CLT) is a long carbon steel pipe with an inner diameter of 32 mm and outer diameter of 42 mm. The insulation is wrapped around the evaporator for preventing thermal losses. Heat flux is given to evaporator through plate type heater using a power supply. Amount of input heat flux is controlled with the help of a controller on the control panel. The heat removal section (condenser) of the thermosyphon consists of an enclosure surrounding a plate type heat exchanger. The fan is used for the heat removal from the condenser section through forced air convection. There is a pressure transmitter to measure the loop pressure and 20 thermocouples to measure temperatures at 20 different locations. All these thermocouples are connected to the data acquisition system which is then connected to a personal computer for displaying the data. All experimental data are recorded and stored in computer system till the steady-state condition is achieved. Figure 1a shows a schematic diagram of the experimental setup and Fig. 1b shows the actual set up picture. The abbreviations mentioned in the Fig. 1 are: PRV: Pressure relief valve, VL: Vapor line length, LL: Liquid line length, E-1: Evaporator 1 and E-2: Evaporator 2, PC: Personal computer.

Before charging the thermosyphon, gases and air present in a loop are removed by the vacuum pump to ensure the perfect operation of the thermosyphon. Vacuuming is down to 0.09 bar (abs). After vacuuming no leakages in the system are ensured. After evacuation, the loop is charged with working fluid as per the required filling ratio. After charging, all the valves are closed tightly. The power supply is given to heat the evaporator section. The heat input is raised gradually to particular heating load. Fans are started. The evaporator surface temperatures are measured at ten different locations by thermocouples. The system pressure is measured by using pressure transmitters at the top portion of the loop. The input and output temperatures of the air flowing over the condenser plates are measured. The flow rate of the working



(a) Schematic diagram (b) Actual set up

Fig. 1 Experimental setup

fluid is measured by the ultrasonic flow meter. The air velocity is measured after it passes over the condenser plates. Temperatures of incoming and outgoing fluid are measured in the evaporator section as well as in the condenser section for per second, time interval until the system reaches thermal steady-state condition. The stored data from PC is used for further analysis. In the calculation of performance parameters, the steady-state values of temperatures are considered. The data reduction and result discussions are carried out in the next sections [10, 11].

3 Data Reduction

The data reduction of the experimental data is carried out by calculating performance parameters like thermal resistance, evaporative heat transfer coefficient, and condenser heat transfer coefficient.

The system thermal resistance (k/W) of the thermosyphon is calculated using the equation:

$$R_{sys} = \frac{(T_e - T_c)}{Q_e} \tag{1}$$

Here, evaporator temperature T_e is taken as the average of all surface temperatures of evaporator (T_1 to T_{10}), and condenser temperature T_c is taken as average of surface temperatures at condenser inlet and outlet (T_{16} and T_{17}).

The heat transfer capacity of an evaporator section for closed-loop thermosyphon is determined by the heat transfer coefficient (h_e) [7].

$$h_e = \frac{Q_{avg}}{A_e \times (T_e - T_v)} \tag{2}$$

Here, T_v is average adiabatic temperature (T_{15} and T_{16}), i.e., vapor temperature between evaporator and condenser. A_e is the surface area the evaporator.

The heat transfer capacity of the condenser section for closed-loop thermosyphon is determined by the heat transfer coefficient (h_c) which is obtained as [7]:

$$h_c = \frac{Q_{avg}}{A_c \times (T_v - T_c)} \tag{3}$$

The surface area of the condenser (A_c) is calculated by from the surface area of the ten condenser plates.

4 Results and Discussions

Analysis of the closed-loop thermosyphon (CLT) system is carried out to understand the thermal behavior of the thermosyphon system and to calculate performance parameters such as thermal resistance, evaporative heat transfer coefficient (HTC), and condenser HTC for different working fluids. In the present work, the closed-loop thermosyphon (CLT) system is designed and developed to explore its possible application in the cooling of huge computational clusters. Assuming that the amount of heat to be removed is in the range of 0.5–4.00 kW, the system is designed with basic components such as evaporator, condenser as shown in Fig. 1. The experimentation is carried out by filling ratio (FR) in the range of 30–80% in the step of 10% at various heat inputs of 0.5–2 kW with a step of 0.5 kW for each evaporator and adiabatic length (vapor line length) of 200 mm. The working fluids used for the experimentations are distilled water, acetone, methanol, and ethanol. The comparative study of these different working fluids is reported in this section. The plots drawn in this section are representative of the result. Filling ratio 30% and heat input ranging from 0.5 to 2 kW is taken as representative of the results, similar trends may obtained from the other configuration.

4.1 Thermal Resistance

Thermal resistance is a function of temperature difference between evaporator and condenser section and heat input. Variation of thermal resistance with heat input is plotted for different working fluids at the filling ratio (FR) = 0.3 (30%) and at the adiabatic length of 200 mm as shown in Fig. 2. It is noticed that for all the working fluids thermal resistance decreases with an increase in heat input. At smaller heat input thermal resistance is higher as large number liquid molecules in the evaporator section become obstruction for transfer of heat. It is further noticed that thermal resistance is higher for the methanol at all the heat inputs and it is lower for acetone for all heat input except at 2 kW. Thus, acetone is better fluid comparatively as its thermal resistance is lower within this range of heat input. The thermo-physical characteristics of methanol are more heat resistive than others whereas thermo-physical characteristics of acetones are more heat conductive than other working fluids.

4.2 Evaporative Heat Transfer Coefficient (H_e)

Evaporative heat transfer coefficient's (HTC) variation with heat input at FR = 0.3 and at the adiabatic length of 200 mm is shown in Fig. 3. Water shows several orders of magnitude greater evaporative heat transfer coefficient than other working fluids

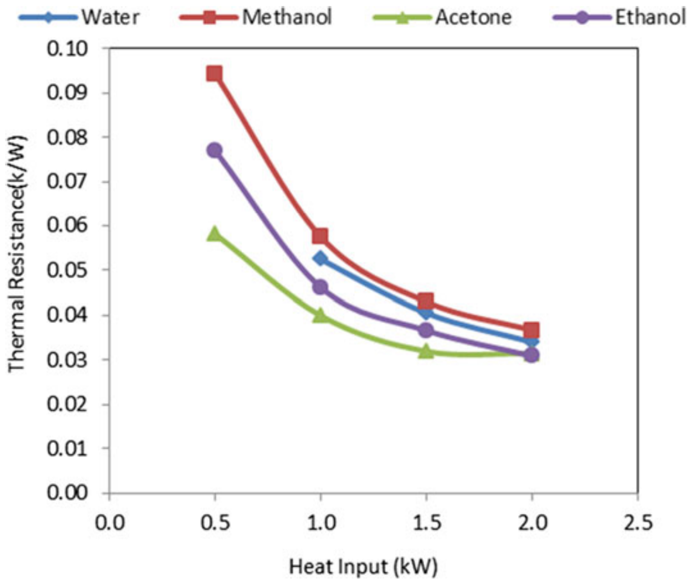


Fig. 2 Thermal resistance (k/W) variation with heat input (kW) at FR = 0.3

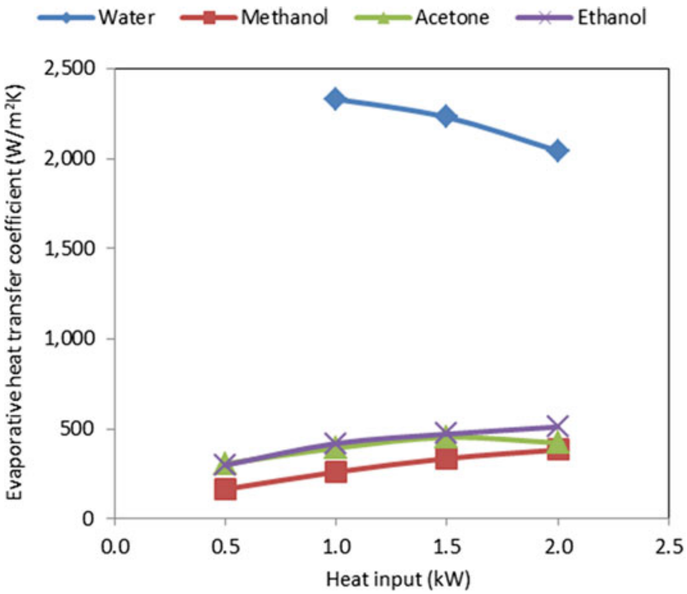


Fig. 3 Evaporative HTC (W/m^2K) variation with heat input (kW) at FR = 0.3

and its trend is different than remaining other three fluids. For distilled water, with the increase in heat input, evaporative heat transfer coefficient decreases slightly, whereas with the increase in heat input evaporative heat transfer coefficient (HTC) of acetone, methanol, and ethanol increases. The heat-carrying capacity of water is higher than other fluids, therefore, water having higher evaporative heat transfer coefficient than another and also its heat carrying capacity decreases slightly with an increase in heat input. The saturation point of water is higher; therefore it is having a higher heat transfer coefficient and also its specific heat decreases with the increase in heat input. Therefore, its evaporative heat transfer coefficient decreases with the increase in heat input. The specific heat of low saturation point fluid is lower than water therefore there heat transfer coefficient is significantly lower than other fluids.

4.3 Condenser Heat Transfer Coefficient (H_c)

Condenser heat transfer coefficient as a function of heat input at FR = 0.3 is shown in Fig. 4. Water shows a much higher condenser heat transfer coefficient (HTC) than other working fluids. With the increase in heat input the condenser heat transfer coefficient increases for all the fluids used in this analysis. Comparatively higher condenser heat transfer coefficient of the water should allow maximum heat transfer rate from the condenser than other fluids. Also, it is noticed that condenser heat

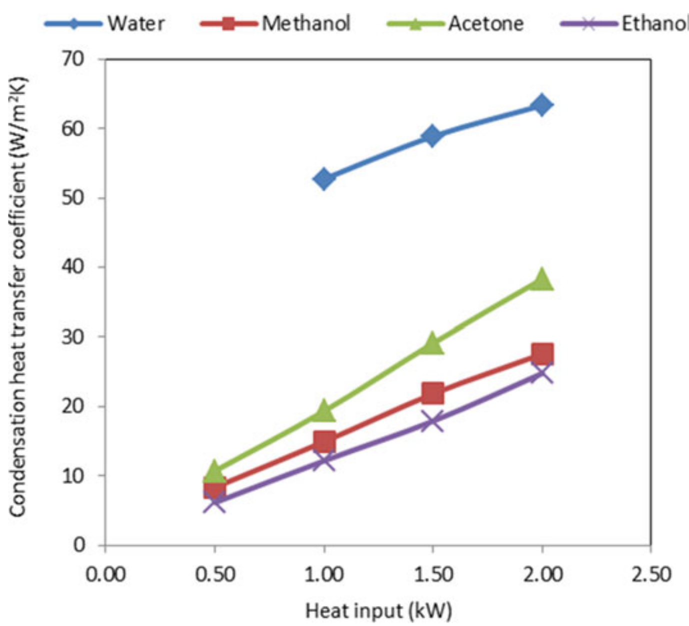


Fig. 4 Condenser HTC (W/m^{2}K) variation with heat input (kW) at FR = 0.3

transfer coefficient is lower than evaporative heat transfer coefficient because film-wise condensation start from the adiabatic section which leads to decrease in the rate of heat transfer which further reduces condenser heat transfer coefficient.

5 Conclusions

The effect of different working fluids on the performance of the closed-loop thermosyphon (CLT) system is investigated experimentally. It is noticed that the thermal resistance decreases with an increase in heat input for all the working fluids used in this experiment. Its value is minimum for acetone and maximum for methanol. Evaporative heat transfer coefficient (HTC) decreases with the increase in heat input for distilled water as a working fluid, but for methanol and ethanol evaporative heat transfer coefficient (HTC) increases with the increase in heat input. The distilled water shows much higher evaporative heat transfer coefficient than other working fluids because it has a higher heat carrying capacity. Condenser HTC increases with the increase in heat input for all the working fluids. Its value for distilled water is much higher than other working fluids, whereas ethanol shows comparatively lower condenser HTC. Also, the condenser heat transfer coefficients are lower than evaporative heat transfer coefficients; this is because of film-wise condensation start in the adiabatic section which leads to decrease in the heat transfer rate.

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