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IISc. THESES ABSTRACTS

Thesis Abstract (Ph.D.)

Formal tools for specification-driven protocol design of distributed computing systems

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1. Introduction

A Distributed Computing System (DCS) is a collection of processor-memory pairs connected by a communication subnet and logically integrated in varying degrees by a distributed operating system and/or distributed database system[1]. The communication subnet may be a geographically dispersed collection of communication processors or a local area network. A processing system at one of the locations of the communication subnet is called a node of the DCS. A DCS covers a wide range of computer systems starting from a multiprocessor system to a long haul computer network. The widespread use of DCSs is due to the advances of cost-effective and efficient communication mechanisms, the development of resource sharing software, and increased user demands for communication, economical sharing of resources, and productivity. In order to fully utilize the advantages of DCSs, satisfactory solution to various issues are to be found out. Some of the significant issues are interprocessor communication, task assignment, distributed databases, and interconnection structure. A good survey of research efforts in the area of DCSs can be found in Stankovic[1]. Out of the various issues mentioned above, this thesis considers the problem of interprocessor communication and develops a methodology for the design and validation of protocols for a DCS.

2. Trends in protocol research

Given a system of cooperating processes such that the cooperation is done through the exchange of messages, a protocol is a set of rules which governs this exchange[2]. Essential requirements of a protocol are that the operations performed by it must be fault-free and it should be able to recover from transmission errors, if any. The development of a protocol typically consists of studies related to its design, specification, validation and performance evaluation. However, research in the area of protocols has been mainly on the specification and validation aspects[3-5]. Protocol specification refers to the description of the protocol behaviour for the interaction among the various nodes or processors of a DCS. The validation of a protocol aims to assure that the designed protocol satisfies its design specifications and operates to the satisfaction of its users. The protocol specification and validation processes do play important roles in the development of a reliable and efficient protocol. But prior to the initiation of these two steps, the protocol should be designed systematically. However, not much work has been reported in this area. In view of this, an effort has been made in this thesis to develop a systematic protocol design procedure for a distributed computing system.

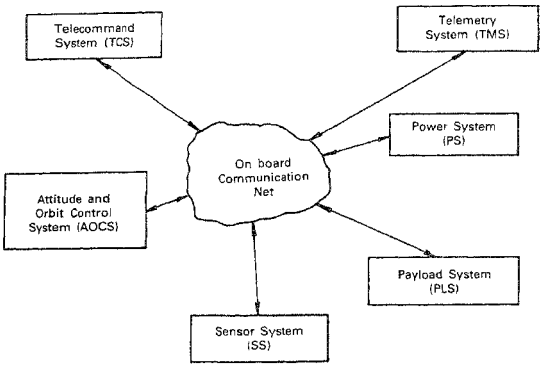

Fig. 1. A typical distributed computing system of a spacecraft.

As a vehicle of discussion of the various techniques developed in this thesis, a typical distributed computing system encountered in an onboard spacecraft application has been considered. However, the techniques developed in this thesis can be used in a variety of other applications like distributed industrial control and distributed data processing. The block schematic of a spacecraft's onboard computing system is shown in fig. 1. It consists of various functionally distributed systems such as Attitude and Orbit Control System (AOCS), Sensor System (SS), Telecommand System (TCS), Telemetry System (TMS), Power System (PS) and Payload System (PLS). Each of these systems has its own processor to carry out the functions designated to it. These functionally distributed systems are interconnected through a common communication net with a suitable topology such that various systems can communicate with one another through more than one path for redundancy purposes.

3. Main results and conclusions

The design and development process of a protocol can be divided into six phases; (i) specification of the distributed computing system for which the protocol is to be designed, (ii) specification of the requirements of the protocol, (iii) protocol design based on the above two specifications, (iv) specification and validation of the designed protocol, (v) performance evaluation of the protocol and (vi) hardware and/or software implementation. This thesis addresses itself to the first four phases of the protocol design and development problems.

The technique developed here for the specification of the DCS is based on matrix and set theoretic concepts. This method is shown to be superior to the ones reported in the literature. The DCS is characterized by properties such as concurrency, strong concurrency, exclusiveness and sequencing. A 6-tuple model to specify a DCS is presented and methods are given to compute the above properties of the DCS from this model. Further, the proposed specification methodology allows us to detect inconsistencies in the system specification and deadlocks caused due to improper specification during the initial phase of the design of the protocol. A similar specification approach is followed to describe the requirements of the protocol which

makes the protocol design procedure simple and straightforward. The approach followed for specifying the protocol requirements allows us to precisely define the protocol requirements for a complex distributed system. Requirements are grouped into various protocol attributes such as the layer hierarchy, the message types, the response types and the action types. The matrix operations defined over some of these attributes together with the attributes of the system specifications facilitate us to develop a simple and systematic design procedure.

The protocol design is also characterized by various attributes. Significant among them are communication among the various layers, checks for error-free transmission/reception, checks for the possibility of concurrent execution of some processes and generation of response signals. A Petri net (PN)[6,7] model for each of these attributes has been developed. These individual models are then combined together to form the complete model of the protocol. This modular development concept reduces the complexity of the design process and provides flexibility in terms of addition/deletion of any specific attribute. Although it is intended to make the protocol design procedure as general as possible, the design procedure cannot be made entirely independent of the application environment. However, the procedure developed in this thesis can be adopted to other similar applications.

As mentioned above, Petri net-based approach is used to develop a model for the protocol and such a model has been used for the validation of the protocol. The tools used for the validation of the protocol are based on Petri nets and their invariants. Computation of invariants of a large Petri net is quite complex involving solution of a number of simultaneous equations. But this thesis presents simple methods for computation of invariants by applying the proposed net reduction techniques. Particular invariants are required to prove a specific property of the PN. In this thesis, we develop a simple technique to find the desired invariants. The invariant is found in two steps. In the first step, a newly defined subnet called RP-subnet is selected such that the selected subnet can have an invariant which is also an invariant of the original net. In the second step, the selected RP-subnet is reduced to a smaller one using the proposed reduction rules and then the reduced subnet is analyzed. The selection of the subnet is governed by the properties to be proved. Since the selected subnet, in general, has smaller number of places and transitions, it is easy to find the invariant for that subnet either using the technique proposed in this thesis or by solving the simultaneous equations corresponding to the subnet only. The rules and techniques for the selection of a subnet are based on the theoretical results developed in our work. The proposed technique is also useful for finding the spanning set of invariants for the entire net which covers all the places in the net. It is felt that the proposed technique will simplify the analysis of most of the practical system models and in most of the cases it may perform better than the method of solving simultaneous equations proposed in the literature. However, a detailed study in this direction has not been attempted in this work. Colored Petri Nets (CPNs) are useful for modeling systems having a large number of similar structures[8,9]. CPNs and their invariants are also used to analyse the protocol developed. This thesis presents a technique for computation of invariants of CPNs. These invariants are used to analyse the properties of CPNs. Also, the techniques for reduction of CPNs into simpler nets are discussed and invariant relationships between the original net and the reduced net are developed. This involves finding the generalized or pseudo-inverses of arc matrices of CPNs. The invariants of CPNs are then computed using the invariant relationships. The approach presented for computation of invariants of CPNs is motivated by the techniques developed for computation of invariants of PNs.

The process of verifying the properties of the protocol is called validation of protocols. The designed protocol is validated using a Petri net-based approach[10]. The protocol is validated in two phases for the sake of simplicity and easy understanding. In the first phase, the protocol for a single message type is considered for validation using the PN. In the second phase, a relatively

complex protocol to handle more than one message type is validated using the CPN, as the PN approach yields a complex net. In both these phases, invariant-based approach is adopted for proving the properties of the protocol. The validation performed on the designed protocol confirms the liveness, deadlock freeness, 1-boundedness or safeness and recovery from failure properties of the protocol. For the sake of illustration, only one failure mode, *i.e.*, the corruption of messages at the receiving end is considered. However, on similar lines other modes of failure can also be considered in the design. The methodology developed in this thesis can also be used in other DCS applications such as distributed industrial control and distributed data processing.

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Thesis Abstract (M.Sc. (Engng))

An expert information retrieval system by S. Sudha.
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1. Introduction

Most information retrieval systems (abbreviated IR systems) require the users of the system to pose their query as a complex boolean expression of keywords[1]. Such a boolean expression specifies to the system the information needs of the user and is called a user's profile. The construction of such a profile requires the use of a thesaurus of keywords in a subject area. The major component of a thesaurus is a main index which lists all key terms with cross-reference

relationships to other terms. The major relationships indicate hierarchy (narrow, broad term) and synonomy. Other components of the thesaurus include related terms and the top term in the hierarchy. End users of IR systems are normally unwilling to learn the intricacies involved in using a thesaurus, and then employ the various indices of a thesaurus effectively, as it is time-consuming. This factor makes it extremely hard for a novice or casual user to get the information he needs quickly. To overcome this problem information centres which have access to on-line retrieval systems employ information specialists as consultants. A specialist is expected to be familiar with the retrieval systems and their thesauri and with the vocabulary that may be used by the various potential users of the system. The consultant gets from the user a description of his problem or his information need. This may include a brief description of his work followed by a list of some important keywords and cited authors in his area. The main purpose of this interaction is to arrive at the index terms that could be used in the search to retrieve articles that are relevant to the user. The consultant, after the initial interactive session with the user, consults the thesaurus to determine equivalent terms. In case a certain term is not present in the thesaurus he employs the additional knowledge and experience he may have to specify the user's profile which is usually formulated as a boolean sum of products of index terms. Having arrived at the profile, in order that the user may make judgements, sometimes the specialist is required to explain the reason for including certain terms instead of the original term suggested by the user. Feedback from the user is subsequently used to improve his query.

There are some problems associated with this technique of creating a profile. The information specialist himself is not a subject expert and has to rely on the dictionary and the thesaurus to make his decisions. The whole operation is time-consuming and results often in a poor profile leading to retrieval of a lot of irrelevant information and missing relevant information.

With rapid increase in on-line information retrieval services, the task of the information specialist has substantially increased. There is also a serious dearth of experienced information specialists. Further it is desirable to provide the expertise of an information specialist to a user at a time and place where he needs it. It is thus worthwhile to explore methods of integrating the 'expertise' of information specialists and create a 'user-friendly' system which would facilitate a user to create his own profile interactively with the computer. This paper describes the design of such a system. The designed system uses the expertise of an information specialist, a subject expert and that of the user. The subject specialist's knowledge is embedded in a knowledge-base organised as an interconnected graph of index terms. The information specialist's knowledge is embedded in decision rules. These rules were obtained after studying and analysing the actual work of a specialist. The user's expertise is gleaned from his reply to queries and his feedback on retrieved abstracts.

An expert system reported in Shoval[2] deals with the problem of query formulation for an IR system. The system provides a user who has an information need with advice as to which terms to use to express his query. It, however, does not make any decision regarding the boolean operators connecting the different terms. Furthermore, the fact-base has not been constructed with a subject expert's assistance. The system reported here has been developed on the basis of Swanson's observation[3] that "it is far more reasonable to design library representations on the basis of the way in which the users tend to organize the subject matter than the way in which indexers imagine that it ought to be organised".

2. System overview

Expert or knowledge-based systems are artificial intelligence terms for computer systems which model the reasoning of experts in a given field. They are high performance programs in restricted

professional domains with an emphasis on the knowledge that underlies human expertise[4]. Such a system ideally has the following features:

(a) It contains a knowledge-base of facts available to experts in the field organised appropriately.

(b) It contains inference rules to be applied on the knowledge-base depending on the data input by the user. These may be heuristic rules applied by an expert while tackling a problem in his domain.

(c) It provides an explanation of its inferencing technique.

(d) It has a facility to expand its knowledge-base.

(e) It is user-friendly.

(f) It has the capability of learning and improving its reasoning or inferencing capability.

The system described in this paper is an expert system named AEIRS (An Expert Information Retrieval System). It incorporates the expertise of the information specialist into the system

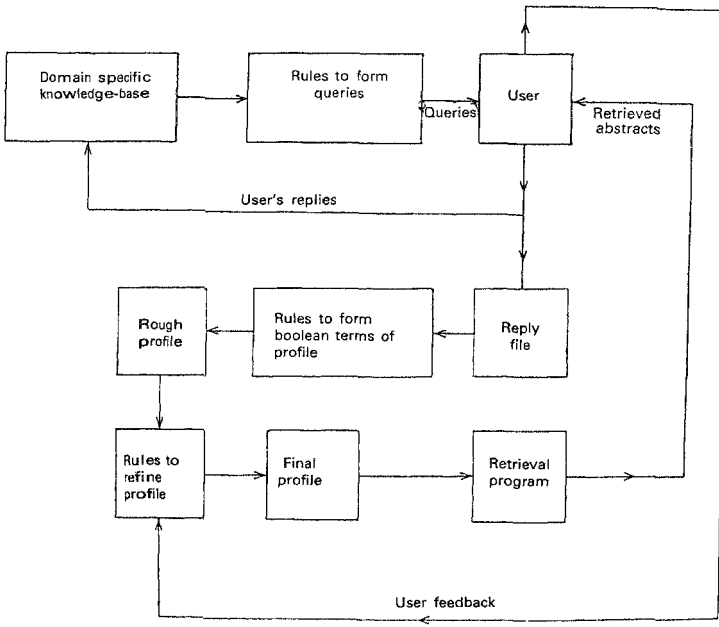

FIG. 1. Block diagram of AEIRS.

thereby assisting the user to formulate the query to be input to the program which retrieves articles/abstracts relevant to him.

A block diagram of the system is given in fig. 1. The subject expert's knowledge is contained in a Domain-Specific Knowledge-base (DSK) in which the index terms are stored hierarchically. The interactive session with the user is guided by the first set of rules which form queries to be answered by the user. These queries initially assist the user in determining relevant keywords. Information from the user regarding the combination in which he wants the keywords to occur is then obtained by asking another series of queries generated using a second set of rules. The user's replies in both the cases are stored in the block, termed the reply file. A rough profile of the user is formulated at this stage. The information specialist's decision rules, contained in a third set of rules, are subsequently applied to refine the profile. This profile is then fed to the retrieval program which searches its document base and displays the retrieved articles to the user. Feedback from the user is obtained to refine his profile further. At this stage, the system can also explain its reasoning procedure if the user desires it. New terms selected by the user from the document displayed to him are stored by the system. Facility exists for incorporating these in the DSK base at a later date.

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Thesis Abstract (M.Sc. (Engng))

Image reconstruction from limited range and noisy projections: A stochastic estimation approach

by N. Rajeevan.
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Department: Electrical Engineering.

1. Introduction

The reconstruction of a two-dimensional function from a set of its projections is a problem encountered in many scientific fields. Radon inversion formula gives a unique solution to this problem provided continuous projections are available over the complete projection range of 360°. In practice, projections can be obtained only at discrete angles and each projection is a sampled version of the continuous projection. The transform technique algorithms, such as Direct Fourier Inversion (DFI), Convolution Backprojection (CBP), and Rho-filtered Layergram (RL) methods use uniformly sampled projections at regular angular intervals over the full range.

In many practical applications, especially in radiological imaging, the projections may not be available over the full range. In these cases the reconstruction from projections is an ill-posed problem[1]. The inversion algorithms based on transform techniques will not give good

reconstructed images, when the measurement data is incomplete. The series expansion techniques, such as the Algebraic Reconstruction Technique (ART), are based on discrete modelling of the measurement process and they iterate through the measurement data to obtain better reconstructed images. Though these algorithms do not require the regularity of the projections, they have limitations in the presence of noise in measurements. The ill-posed nature of the limited angle reconstruction problem makes the series expansion techniques unstable. Hence, the reconstructions from noisy projection data using these algorithms are not satisfactory.

The problem of reconstruction from limited range and noisy projections can be formulated as a stochastic estimation process by treating the measurements, noise in measurements, and the object as sample realisations of some stochastic processes[2]. In this case any *a priori* information regarding the nature of the object along with the knowledge of the statistics of the noise can be incorporated in the reconstruction procedure. Such estimation techniques are more appropriate when the measurements are noisy. However, these estimators are not used in commercial applications due to their excessive computing time and memory requirements. In this thesis a particular stochastic estimation technique, the Minimum Variance Estimator (MVE), is considered and its efficient implementation in a limited range and noisy projection situation is discussed.

2. A fast minimum variance estimator for image reconstruction

The measurement equation given by

$$\mathbf{y} = \mathbf{A}\mathbf{x} + \mathbf{v}$$

relates the measurement vector $\mathbf{y}$ to the object vector $\mathbf{x}$ through the projection matrix $\mathbf{A}$ and the measurement noise vector $\mathbf{v}$. Using this model the minimum variance estimator $\hat{\mathbf{x}}$ of $\mathbf{x}$ is given by

$$\hat{\mathbf{x}} = E[\mathbf{x}] + \mathbf{P}_0\mathbf{A}^T(\mathbf{A}\mathbf{P}_0\mathbf{A}^T + \mathbf{R}_v)^{-1}(\mathbf{y} - \mathbf{A}E[\mathbf{x}])$$

where E is the expectation operator, $\mathbf{P}_0$ the *a priori* estimate error covariance matrix and $\mathbf{R}_v$ the noise covariance matrix. The implementation of this estimator requires inversion of the measurement covariance matrix $\mathbf{R}_{yy}$, where

$$\mathbf{R}_{yy} = \mathbf{A}\mathbf{P}_0\mathbf{A}^T + \mathbf{R}_v.$$

Hence, a direct implementation of the MVE is highly complex and impractical.

One of the possible solutions to this problem is to implement the MVE as a sequential algorithm using the Kalman filter. In this formulation the Kalman filter is used as a one-step predictor, where the projection data is considered as the observation made on the state of the system, which is the object function itself. This way the direct inversion of the covariance matrix is completely avoided.

The other approach, the block implementation of the MVE, is the main subject of the thesis. In this method the measurement covariance matrix is structured to make the MVE amenable for computer implementation. Using a random object assumption the correlation between two measurements is considered to be proportional to the area of intersection of the corresponding beam paths. With complete data, the $\mathbf{R}_{yy}$ matrix can be structured as a Block Circulant Matrix (BCM). This matrix can be easily inverted using fast Fourier transform techniques. However, with limited range projections the BCM structure of the $\mathbf{R}_{yy}$ matrix is lost, rendering the above method unsuitable in such situations. A new efficient method for image reconstruction from limited range and noisy projections is proposed in the thesis[3,4]. In this method the $\mathbf{R}_{yy}$ matrix is structured as a

Toeplitz-Block Toeplitz (TBT) matrix. The TBT structure is achieved by using parallel beam projections with all the beam paths having identical widths. With this structure of the R_{yy} matrix a fast and storage efficient recursive algorithm for the MVE implementation is presented. The efficiency of this algorithm is achieved by exploiting the persymmetry property of the TBT matrix and its inverse. The efficient MVE implementation for image reconstruction from limited range and noisy projections is discussed.

3. Simulation results

The efficacy of the minimum variance estimator for image reconstruction from limited range and noisy projections was examined using computer-simulated experiments. A simulated phantom and its noisy projections were used in this study. The convolution back projection algorithm was found to be unsuitable for limited range projection situation. The quality of reconstruction using the proposed minimum variance estimator was compared with that produced by the ART, for various projection ranges and noise levels. In all these cases the proposed algorithm outperformed the ART on root mean square error criterion.

4. Conclusion

For image reconstruction from limited range and noisy projections the stochastic estimation techniques are shown to be more appropriate than the deterministic algorithms. The thesis presents an efficient minimum variance estimator and proves its superiority over the algebraic reconstruction techniques.

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Thesis Abstract (Ph.D.)

Photovoltaic pump optimization techniques: Some studies and results by S. Ramesha Bhat.
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1. Introduction

Solar pumps like wind-driven, solar-thermal, photovoltaic, etc., have attracted considerable attention for lifting water for irrigation and other purposes, in the past decade. Of these, the

photovoltaic pumps have received importance, due to major developments in the field of solar cell materials and technology[1]. A number of experimental photovoltaic pumps are already in use in several parts of the world. Almost all these systems use dc motor-driven pumps powered by solar array. dc motors generally have more maintenance problems due to the commutator and brushes. Due to recent developments in ac drives, the use of induction motor which is known for its high reliability has gained attention in such applications.

Apart from the features of low cost, ruggedity, and virtually no maintenance needs, the induction motors are available in a wide range of power ratings However, as the array power is dc, it has to be converted into ac form at a suitable frequency to drive the induction motor. This requires the use of an appropriate dc–ac inverter. It is advantageous to control the supply frequency to the motor, so as to minimize the associated power losses. It is also beneficial to make use of a suitable power conditioner to provide a proper interface between the photovoltaic array and the induction motor. However, it is observed from published literature that, so far, detailed studies have not been conducted on photovoltaic pumping systems using induction motors. A critical review and examination of the photovoltaic pumping system using an induction motor has shown that there is considerable scope for studies in the following areas:

a) Characterization of solar cell arrays;

b) Choice and analysis of a suitable power conditioner;

c) Analytical studies on induction motor-pump subsystem;

d) Maximum power point tracking algorithms;

e) Factors leading to optimization of system performance.

The recent developments in power electronics and drive systems as well as microprocessors have opened up new opportunities in the system development. These have been exploited in the analysis and development of a complete photovoltaic pumping system using induction motor. A study of maximum power point algorithms leading to the choice of a suitable algorithm has also been presented. The system performance curves for the pump operation are evaluated and daily flow computations are carried out for different system heads using the available insolation data. Significant results of this study and conclusions drawn therefrom are summarised below.

2. Analytical studies[2]

2.1 Induction motor v-f control

A detailed study on the v-f relationship for induction motor control using the pump as the load has led to the following observations:

(i) There exists an optimum v-f relationship for a given system head which minimizes the motor power input.

(ii) It is possible to make use of the maximum power available from the solar array, if proper attention is paid for the choice of motor rating in relation to the system head *i.e.* the rated motor power should correspond to the minimum expected system head.

(iii) While the motor power input can be optimized by choosing an appropriate v-f relationship for each system head, only one optimum v-f relationship can be used without sacrificing the system performance significantly.

2.2 Power conditioner

A detailed analysis of the power conditioner has led to the following result:

First it is shown by a simple analysis that the optimization at the load end corresponds to optimization at the source end, only if the efficiency of the dc -dc converter does not vary with the duty cycle. Analysis of the non-ideal dc–dc converter used as a power conditioner has shown that efficiency varies with the duty cycle. However, for the non-ideal dc–dc converter used in this investigation, the deviation from the ideal case is found to be so small that the load optimization also leads to source optimization. This results in a simple implementation of the maximum power point tracking controller, as the load voltage variation corresponds to load power variation.

2.3 PV panel characterization

A solar simulator with an I-V measurement system is used to obtain the various parameters of the PV panels. Following are the important results:

The efficiency of the panel is higher during the morning hours (0800–1000 h), and decreases slightly during the rest of the day. This is attributed to an increase in temperature of the cells as the insolation increases. Thus, even though the available power increases with the increase in insolation, it is not possible to extract the rated power from the panels during higher insolation. And the temperature effects cannot be ignored. It is important to note that the cells are priced in terms of the peak power at a standard insolation of 1 KW/sq.m and a temperature of 28°C. In tropical countries, the cell temperature can go up to 60–70°C at higher insolation like those at local noon and hence the available power degrades. To remedy this situation, one can consider cooling the array, *e.g.*, by circulating the pumped water through the array. However, it becomes necessary to design special back panels to carry out this heat transfer. Also, special precautions have to be taken to avoid creating extra head for this purpose.

3. Experimental results and performance evaluation

A complete photovoltaic pumping system with induction motor drive has been developed and installed following analytical studies. Algorithms for maximum power point tracking were studied using this set-up and the performance characteristics of the system are summarised below:

3.1 MPP algorithms

Two types of algorithms *viz.*, the dynamic and quasi-dynamic types have been implemented using uP control. The significant results are:

i) Dynamic tracking which 'hunts' around the maximum power point is not a stable control technique as its performance is not satisfactory under sudden changes in solar insolation.

ii) Quasi-dynamic tracking technique indeed results in an improved performance as it avoids the 'hunting' problems.

3.2 System performance evaluation

Motor pump characteristics for different operating heads are measured for this system and the daily flow computations are carried out using the available insolation data. The important results of this study are:

i) There exists a threshold power below which the water output is zero;

ii) The threshold power increases with the operating head;

iii) The daily water output obtained from the pump at a lower head is more than that when operated at a higher head. Also, when the insolation is low, higher head can result in zero water output;

iv) The overall efficiency of the system is found to be better for a lower head than for a higher head. This is in spite of the fact that the pump efficiency decreases at lower heads. The reason for this behaviour appears to be the lower threshold power at lower head which results in the pump operation for a longer duration on any day. Thus a suitable pump has to be carefully chosen by looking into its flow-power (Q–P) diagrams and the system head. It may be noted that the overall, all day efficiency of this system approaches that of other systems reported in the literature.

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Thesis Abstract (M.Sc. (Engng))

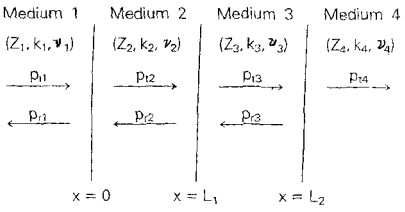
A feasibility study on the synthesis of acoustic absorbers based on layered composites by C. Guruprasad.
Research supervisors: M. Satyam, K. Ramkumar and D. B. Ghare.
Department: Electrical Communication Engineering.

1. Introduction

Acoustic absorbers find applications in auditoria, environmental noise control and as noise suppressors in a variety of equipment[1,2]. In most of these applications it is necessary to suppress only certain frequency components through the use of absorbers. This implies that the absorbers must have specific frequency–absorption characteristics. The absorbers that have been made so far are based on trial and error methods[3–5]. There seems to be a need for developing a methodology by which an absorber with frequency–absorption characteristics can be designed. One of the methods of realizing this is based on the use of composite materials in which more than one material is present. Composite materials are of three types: (i) Layered composites (ii) Fibrous composites (iii) Particulate composites. An effort is made to study the acoustic behaviour of layered composites with a view to explore the possibility of synthesizing absorbers with required characteristics.

2. Acoustic wave propagation through layered composites

In the first instance, the propagation of acoustic waves through a two-layer composite backed by a material with highly reflecting characteristics has been considered. The type of structure considered is shown below:



For this type of composite, referred to as Type A absorber the expressions for reflection coefficient, absorption and impedance as a function of frequency have been derived through the solution of wave equation and are given below.

$$RC3 = \frac{e^{-T_3(\nu_3 + jk_3)}(Z_4/Z_3 - 1)}{(Z_4/Z_3 + 1)}$$

$$RC2 = \frac{e^{-T_2(\nu_2 + jk_2)} Z_3/Z_2 \dfrac{1 + RC3\, e^{-T_3(\nu_3 + jk_3)}}{1 - RC3\, e^{-T_3(\nu_3 + jk_3)}} - 1}{Z_3/Z_2 \dfrac{1 + RC3\, e^{-T_3(\nu_3 + jk_3)}}{1 - RC3\, e^{-T_3(\nu_3 + jk_3)}} + 1}$$

$$RC1 = \frac{Z_2/Z_1 \dfrac{1 + RC2\, e^{-T_2(\nu_2 + jk_2)}}{1 - RC2\, e^{-T_2(\nu_2 + jk_2)}} - 1}{Z_2/Z_1 \dfrac{1 + RC2\, e^{-T_2(\nu_2 + jk_2)}}{1 - RC2\, e^{-T_2(\nu_2 + jk_2)}} + 1}$$

where,

$RC3$ is the reflection coefficient at the interface I_{34},

$RC2$ is the reflection coefficient at the interface I_{23},

$RC1$ is the reflection coefficient at the interface I_{12},

ν_2, ν_3 are the attenuation constants of medium (2) and medium (3), respectively.

T_2, T_3 are the thickness of medium (2) and medium (3), respectively.

Z_1, Z_2, Z_3, Z_4 are the acoustic impedance of media (1)–(4), respectively.

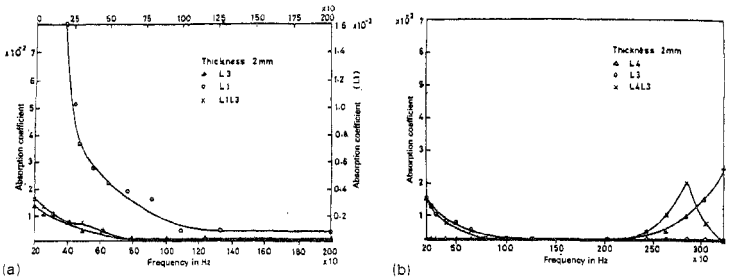


FIG. 1. Computed variation of absorption coefficient with frequency for (a) Type A1, and (b) Type A2 composites.

The absorption coefficient for the composite is derived from the final reflection coefficient of the composite. The variations of these parameters with frequency have been calculated using the DEC system-1090 computer for different combinations of the layer that are used in the absorber.

2.1 Type A absorbers

Based on the characteristics of the individual layers used, Type A absorber has been further subdivided into two types — Type A1 consists of layers both of which have similar impedance *vs* frequency characteristics: Type A2 consists of layers in which one of the layers has an impedance which increases with frequency and the other has an impedance which decreases with frequency. Through the calculations it has been found that Type A1 absorbers generally maintain the trends of the characteristics of the individual layers and only the actual variation of impedance and absorption with frequency is modified.

On the other hand, in Type A2 absorbers, it is found that the impedance as well as absorption characteristics exhibit peaks and valleys which are not present in the individual layers (fig. 1). It has also been found that the frequencies at which these peaks appear and the magnitudes of the parameters at the peaks and valleys depend upon the thickness of the layers and the ratio of impedance of these two layers (fig. 2). The same analysis has also been extended to three-layer cases and the expressions for reflection coefficient, absorption coefficient and impedance have been derived. However, no detailed analysis has been carried out on three-layer composite absorbers as these studies did not provide any additional features.

2.2 Type B absorbers

It may be noted that in the layered composite discussed above the individual layers are stacked in such a way that the acoustic energy encounters one layer after another while it is propagating from the front surface of the composite to the reflecting end. Another type of layered composite which can be considered as an absorber is one in which two different materials are stacked together in such a way that the acoustic energy encounters both the layers simultaneously and propagates in two different channels, one of each medium. The behaviour of such a composite,

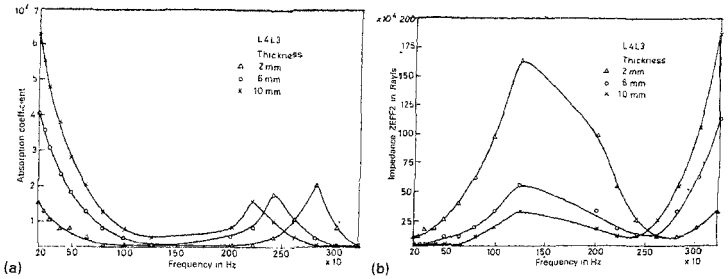


FIG. 2. Computed variation of (a) absorption coefficient (b) impedance with frequency for type A2 composite.

referred to as Type B absorber, consisting of a hard material like ceramic surrounded by a soft material like rubber, has been analysed. In this case it has been found that the total absorption depends on the relative volumes of the two materials and their absorption coefficients (fig. 3). This provides a single method of changing the absorption characteristics of a composite material. In the simple analysis that has been carried out, the effect due to coupling between the two materials at the interface has been neglected.

3. Experimental

To verify some of the ideas developed through the analysis, a few composite absorbers based on materials like rubber, quartz and wood fibre have been prepared and their absorption characte-

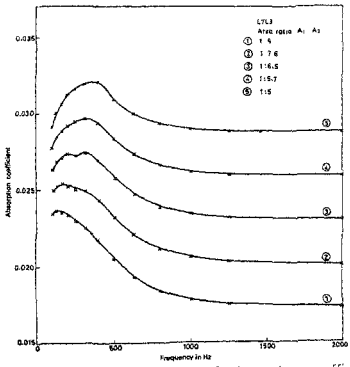


FIG. 3. Computed variation of absorption coefficient with frequency for type B composite

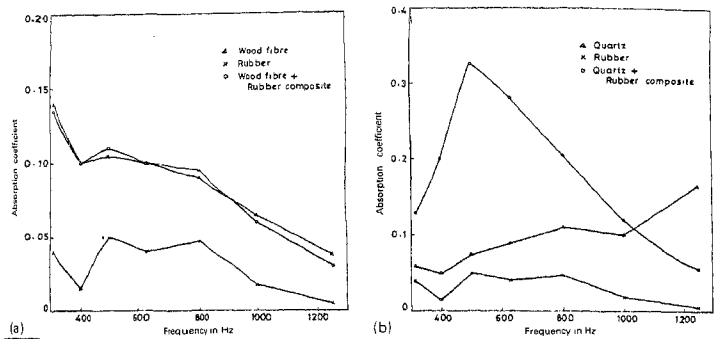


FIG. 4. Measured variation of absorption coefficient with frequency for (a) Type A1 and (b) Type A2 composites.

ristics have been measured, with the impedance tube in the frequency range 400–2000 Hz. It has been found that in the case of Type A1 absorbers the measured characteristics show peaks which are not present in the individual layers (fig. 4). Also it has been found that in the composites of Type B, the absorption changes with the relative volumes of the materials that are present.

4. Conclusions

This work has established that it is possible to synthesize acoustic absorbers with required frequency-absorption characteristics through layered composites at least in the frequency range investigated.

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