J. Indian Inst. Sci., May–June 2001, **81**, 335–369.

IISc THESES ABSTRACTS

Thesis Abstract (Ph. D.)

Interlaminar fracture toughness of composites—Higher order shear deformation beam theories
by D. V. T. G. Pavan Kumar
Research supervisor: Prof. B. K. Raghu Prasad
Department: Civil Engineering

1. Introduction

Currently, fiber-reinforced laminated composite structures are being used extensively in a variety of industrial products and structures such as aircraft, automobiles, marine vessels, rocket launchers, pressure vessels and pipes owing to their strength, high stiffness, low weight and good resistance to fatigue and corrosion. The most common problem in these materials is delamination along ply interfaces which may arise due to fabrication defects and impact loading. In general, a delamination will be subjected to crack driving forces resulting from either or combination of mode I (opening or peeling), mode II (sliding or shear) and mode III (antiplane shear). In order to understand the behaviour of laminated composites and to be able to characterize as well as predict failure, the interlaminar fracture toughness (IFT) must be evaluated. For laminated composite structures, a critical value of the strain energy release rate (SERR) known as interlaminar fracture toughness has been found to be more convenient for the prediction of delamination growth. The most widely used test specimen for IFT in mode I is double cantilever beam specimen (DCB). Similarly, end notch flexure (ENF) and end notch cantilever (ENC) specimens are the most common test specimens that have been used for IFT in mode II.

From the available literature, it has been observed that ENF, ENC and DCB specimens have been analysed using both finite element and analytical methods. Most of the earlier studies dealt with unidirectional ENF, ENC and DCB specimens. Recently, a few studies are also available on multidirectional ENF, ENC and DCB specimens. Further, a very few in the past, have attempted to analyse ENF, ENC and DCB specimens using higher-order beam theories. However, analytical studies on the analyses of uni- and multidirectional ENF and ENC specimens using higher (third)-order shear deformation beam theory and multidirectional DCB specimen using higher-order shear deformation beam theory (with quadratically varying transverse displacement over the beam thickness) appear to be not studied till now. Hence, in the present work, it has been attempted to fill up these analytical gaps on the analyses of uni- and multidirectional ENF, ENC and DCB specimens using higher-order shear deformation beam theories to determine IFT of composites.

2. Relevant formulations

The governing differential equations, for classical (CBT), first (FOBT)-, second (SOBT)-, third (TOBT)-order beam theories (SOBT, TOBT are generally called as higher-order beam theories) and higher-order beam theories ($HOBT^{lw}$, $HOBT^{qw}$) (with linearly and quadratically varying transverse

displacement over the beam thickness), have been derived for uni- and multidirectional laminated composites using principle of minimum potential energy and variational principles. Compliance approach has been presented to determine the SERR.

3. Analyses of uni- and symmetric multidirectional ENF and ENC specimens

Stress analyses and uni- and symmetric multidirectional ENF and ENC specimens have been presented using CBT, FOBT, SOBT and TOBT for IFT of laminated composites in mode II. For this purpose, available stress analysis models[1] have been thoroughly revised and modified to analyse ENF and ENC specimens. These models consider only upper halves of ENF and ENC specimens because of the reason that delamination is at midplane and lamination scheme is symmetric about the midplane of ENF and ENC specimens. In addition, in the present study, appropriate matching conditions, in terms of generalised displacements and stress resultants, have been applied at the crack tip by enforcing displacement continuity at the crack tip in conjunction with variational equation. It may be mentioned here that variational approach has been extensively used in the work, which only enabled determination of appropriate boundary and matching conditions which would have been almost impossible otherwise. The compliance and SERR obtained from the present formulations have been compared with the existing analytical, experimental and finite-element results. Also, parametric study has been carried out to study the influence of crack length, ratio of Young's modulus to shear modulus, span-to-depth ratio and fiber orientation on the compliance, SERR and interlaminar shear stress distribution ahead of the crack tip.

4. Analyses of symmetrical multidirectional DCB specimen

Stress analyses of uni- and symmetric multidirectional DCB specimens have been presented using CBT, FOBT, SOBT, TOBT, $HOBT^{lw}$ and $HOBT^{qw}$ for IFT of laminated composites in mode I. For this purpose, an available stress analysis model has been modified to analyse a DCB specimen.[2] This model considers only upper half of the DCB specimen because of the reason that delamination is at midplane and further lamination scheme and loading are symmetric about the midplane of the DCB specimen. In addition, in the present study, appropriate matching conditions have been applied at the crack tip by enforcing displacement continuity at the crack tip. The compliance and SERR obtained from the present formulations have been compared with the existing analytical, experimental and finite element results. Also, parametric study has been carried out to study the influence of crack length, ratio of Young's modulus to shear modulus, span-to-depth ratio and fiber orientation on the compliance, SERR and interlaminar normal stress distribution ahead of the crack tip.

5. Analyses of multidirectional unsymmetric ENF, ENC and DCB specimens

Stress analyses of uni- and multidirectional unsymmetric ENF, ENC and DCB specimens have been presented using CBT, FOBT, SOBT and TOBT derived earlier. Unsymmetry can be either due to arbitrary location of delamination over the test specimen's depth or due to unsymmetric lamination scheme about the midplane of the test specimen or the combination of the two. In addition to the earlier stress analysis models, three other models have been proposed which will take into account the entire ENF, ENC and DCB test specimens, respectively. Two distinct advantages of stress analysis models developed in this section over the stress analysis models of the previous sections are that the following can be considered. They are: i) nonmidplane delamination and ii) unsymmetric

lamination scheme about the midplane of the test specimen. In these stress analysis models also, appropriate matching conditions have been applied at the crack tip by enforcing displacement continuity at the crack tip. The results thus obtained have been compared with those from earlier chapters. Parametric study has been carried out to study the influence of arbitrary delamination location over the depth of the test specimens on the compliance and SERR.

6. Finite- element analysis of unidirectional ENF and DCB specimens

Two-dimensional finite-element analysis of unidirectional ENF and DCB specimens has been presented for various span-to-depth ratios. SERR has been calculated using virtual crack closure technique (VCCT). These SERR values have been compared with SERR values obtained from the present formulations using TOBT and $HOBT^{qw}$ for ENF and DCB specimens, respectively. The objective is to provide a cross check on the performance of the stress analysis models in conjunction with higher-order beam theories for various span-to-depth ratios, vis-a-vis, well-established routinely used finite-element codes.

7. Conclusions

Third-order shear deformation beam theory (TOBT) is in excellent agreement with the existing experimental, analytical and finite-element results and found to be more accurate in predicting IFT particularly when E_{11}/G_{13} ratio is high in the case of ENF and ENC specimens. Higher-order shear deformation beam theory ($HOBT^{qw}$) is in good agreement with the existing experimental, analytical and finite-element results and is found to be more accurate in the case of DCB specimens.

One can use either plane stress type (pl. σ) or plane strain type (pl. ε) assumption to carry out stress analysis in the case of uni- and multidirectional (having only 0° and 90° fiber orientations) ENF, ENC and DCB specimens. pl. σ type and pl. ε type of stress analyses of multidirectional ENF, ENC and DCB specimens differ quite significantly for fiber orientations other than 0° and 90°. pl. ε type stress analysis results are closer to three-dimensional finite-element results when compared to pl. σ type stress analysis results in the case of multidirectional ENF and DCB specimens.

Compliance and SERR increase as crack length increases for uni- and multidirectional ENF, ENC and DCB specimens. Compliance and SERR increase as E_{11}/G_{13} and L/h ratios increase for ENF, ENC and DCB specimens. Given the lamination scheme and crack length, compliance and SERR increase as θ varies from 0° to 90°. The SERR values from shear deformation beam theories approach SERR values from CBT as the value of a, the crack length, increases for ENF and ENC specimens. The compliance and SERR values from shear deformation theories approach CBT's compliance and SERR values as the value of a increases for DCB specimens. In the case of mode II test specimens, TOBT and SOBT give high shear stress at the crack tip which decays exponentially to that from CBT as the distance increases from the crack tip. Similarly, in the case of DCB test specimens, $HOBT^{lw}$ and $HOBT^{qw}$ show high interlaminar normal stress at the crack tip which exponentially approaches zero as distance increases from the crack tip. Peak interlaminar shear and normal stresses increase for ENF and DCB specimens, respectively, at the crack tip as θ varies from 0° to 90°.

The distribution of compliance and SERR for various delamination locations plotted over depth with respect to the midplane is symmetric for symmetric laminates and unsymmetric for

unsymmetric laminates. In uni- and multidirectional symmetric as well as unsymmetric laminates, the values of compliance and SERR, corresponding to midplane delamination, are maximum for ENF and ENC specimens, while they are minimum for DCB specimens.

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Thesis Abstract (Ph. D.)

The variable source area conceptual model for Western Ghats, Karnataka, India by P. H. Sawant
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Department: Civil Engineering

1. Introduction

The objective of this work is to develop a lumped parameter conceptual rainfall–runoff model which accounts for complex hillslope responses such as interception, evapotranspiration, subsurface flow, base flow and in particular variable source area storm flow seepage through micropores and pipes, and can be applied to ungauged catchments as well.

A VSA (variable source area) conceptual model has been developed for catchments Malati (262.6 km^2), Duskinala (503 km^2) and Gowrihole (126 km^2) situated in the Western Ghat region of Karnataka, India. These catchments have a complex network of subsurface and surface flow passages due to biotic activity, resulting in nonHortonian flow. The model requires only daily rainfall and runoff records and no other physical information about the catchment as in the case of physically based model SHE (Systèm Hydrologique Europèen) applied to Narmada subcatchments by Jain *et al.*[1] The daily rainfall values were made available by the Directorate of Economics and Statistics, Karnataka. Measured streamflow for the catchments is made available by Water Resource Development Organization, Karnataka. The daily rainfall series used for the Malati catchment is for the time period January 1, 1985 to December 31, 1994. Gowrihole data are available from January1, 1985 to December 31, 1986 and data period for Duskinala catchment is from January 1, 1986 to December 31, 1988. Since potential evapotranspiration measurements are not available for the catchments, potential evapotranspiration (PET) data series are generated using the following equation

$$PET_n = PET_{min} + \frac{1}{2}\left(PET_{max} - PET_{min}\right)\left(1 + \sin\left\{\frac{2\pi n}{365} - \frac{\pi}{3.25}\right\}\right)$$

where PET_n is the potential evapotranspiration demand on the nth day, PET_{min} (mm) and PET_{max} (mm) are minimum and maximum potential evapotranspiration values during winter and summer, respectively. The split record method was used for model validation.

The modelling approach adopted involves generating a sequence of simulated streamflows along with intermediate variable elements of the rainfall–runoff cycle, namely, (1) watershed model

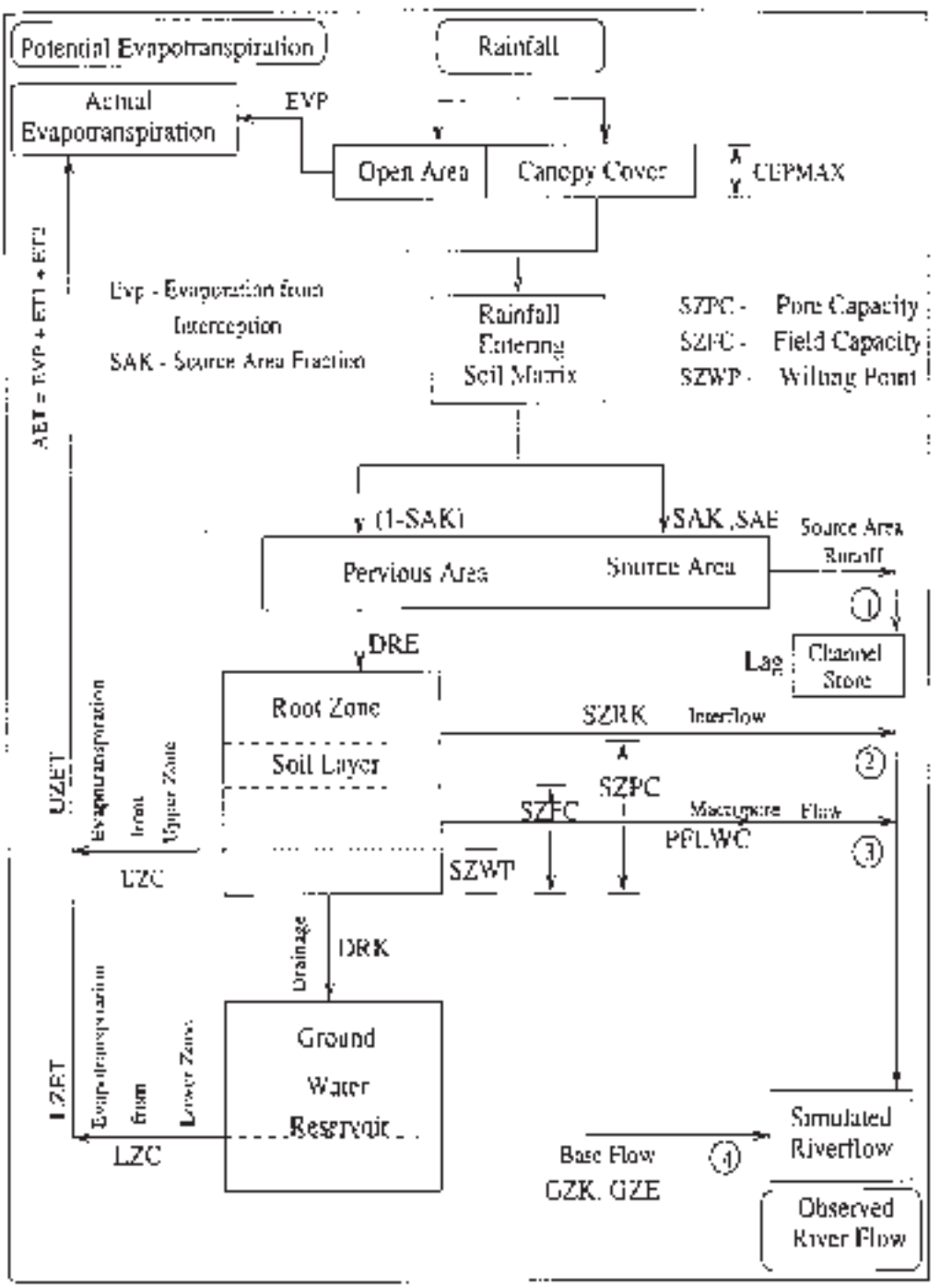

FIG.1. Conceptual VSA model for the forested hillslopes of western ghats.

representation, (2) mean areal rainfall, (3) interception, (4) depression storage, (5) soil moisture storage, (6) infiltration, (7) evapotranspiration, (8) interflow, (9) baseflow, (10) surface runoff and (11) variable source area (Fig. 1). The model parameters are obtained by minimizing the objective function which is the sum of the squared deviations.

$$OF = \sum_{t=1}^{N} (Q_{\text{obs}}^{t} - Q_{\text{sim}}^{t})^2$$

The precipitation decreased by interception gives net rainfall reaching soil matrix. This is distributed partly to depression storage, partly held by the soil matrix and partly going away in the form of overland flow due to formation of source area. A portion infiltrates and some part is accounted for by the evapotranspiration occurring from top soil layer, in proportion to the soil moisture content. Evapotranspiration also occurs from the lower soil zone, i.e. ground water store. Evapotranspiration, interflow, macropore flow and percolation are determined based on soil moisture parameters. The base flow is proportional to the ground water storage. As all these processes occur simultaneously, water balance is checked at every time step. Actual evapotranspiration consists of three components: evaporation, evapotranspiration from lower and upper zones. The simulated riverflow is obtained by adding four runoff components, namely, source area runoff, interflow, macropore flow and base flow. The simulated runoff and model parameters are obtained by minimizing the deviation from actual runoff, by optimizing the given objective function using genetic algorithm (GA). Wang[2] reported the application of GA for calibration of Xinan Jiang model.

The GA used had a population size of 500 individuals, chromosome length of 12 bits (binary bit representation), i.e. descretization up to 2^{12} parts of a given parameter. Multiple crossover, increasing mutation, fitness ranking and steady-state population evolution were used. Convergence criterion of 90% of gene convergence with not more than 25 iterations was adopted. Model parameter set finally selected was based on the results of many optimization runs. Various optimization runs were conducted using different initial random seed so that for every optimization run a new search space is initialized.

Model parameters optimized for Malati catchment are also directly used to simulate riverflow from Gowrihole and Duskinala rainfall data. The results show that the model can be successfully applied to hillslope catchments and is also useful for ungauged catchments (Fig. 2). Table I gives an indication of the model performance in various cases.

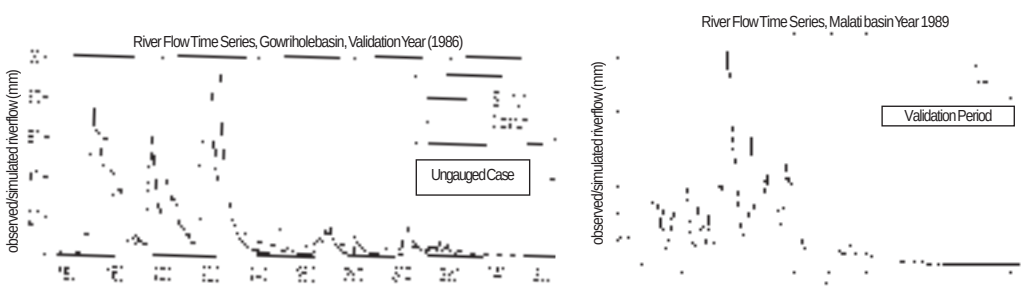

FIG. 2. Time series of observed vs simulated riverflow including ungauged catchment.

Table I
Model performance for all the cases

Catchment	Model parameter	Calibration period(%)	Validation period(%)	Ungauged case(%)
Malati	η	91.32	88.28	–
	CC	95.64	98.04	–
Gowrihole	η	85.35	67.37	72.41
	CC	92.77	84.29	89.31
Duskinala	η	66.43	27.36	24.76
	CC	81.70	58.86	77.65

The results obtained from model calibration show high correlation with observed data. Correlation between observed and simulated riverflow series is more than 95% in the case of Malati basin. Gowrihole and Duskinala simulated river flows show fairly good correlation with the observed one. Model results when used for ungauged case of Gowrihole and Duskinala catchment are comparable with those obtained during calibration. Mass balance difference is less than 5 mm in all the cases.

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Thesis Abstract (Ph. D.)

A general theory for laminated composite smart thin-walled beams by E. Hemalatha
Research supervisors: Profs J. Nagabhushanam and A. V. Krishna Murty
Department: Aerospace Engineering

1. Introduction

Thin-walled composite beams find application in aircraft/helicopter structural components. Methods to analyze these structures range from simple beam theories to three-dimensional elasticity analysis. But theories which are in between the limiting situations of these two are known as thin-walled beam theories and are considered to be particularly attractive for the analysis of these structures. Although thin-walled beam theory has been extensively used for metallic structures,[1] the development of such a theory for composite structures is of recent origin.[2] Most of the studies are limited to specific geometries. There are very few generalized theories which are applicable to any arbitrary cross-section.

Composites being tailorable materials, it is possible to alter their stiffness properties to achieve desired static and dynamic response. Passive control of vibrations by such aeroelastic tailoring is already being practiced. With the availability of functional materials such as piezoelectrics and the possibility of embedding/surface bonding them into laminated composites, the idea of active vibration control using smart structures technology is gaining wide attention.[3,4] An essential prerequisite to design such smart structures is the availability of theoretical models to predict their

performance accurately. A general integrated theory for smart thin-walled beams of arbitrary cross-section is yet to emerge. This work focuses on developing a general theory for laminated composite thin-walled beams of arbitrary cross-section with and without smart features.

2. Formulation

A general theory for laminated composite thin-walled beams of arbitrary cross-section is formulated following the approach of classical thin-walled beam theory.

The governing equations of motion are derived using Hamilton's principle. They are in the form of partial integro-differential equations, since three of the displacement variables U, V and θ are functions of the axial coordinate z and time t, whereas the fourth one ω is a function of z, the contour coordinate s and t. Using the Kantorovich form of Rayleigh–Ritz method they are converted to sets of linear differential equations to different levels of approximation by choosing a suitable function for warp. A method to generate successive approximations to the warp function, proposed by Murty and Rao[5] for isotropic sections, is adopted successfully for composite beams in the present investigation. The method utilizes the mathematical and geometric features of the problem in arriving at the warp function. As a consequence, the influence of secondary effects like shear lag, longitudinal inertia, etc. appear explicitly in the governing equations. This facilitates in assessing the influence of each of these effects on the behaviour of the structure. Such studies help designers to correct the results of simpler theories without going through complicated analytical and numerical studies each time.

The theory is first applied to static and dynamic analysis of laminated composite thin-walled beams without smart features. With the aid of typical examples and comparison with experimental results available, the theory is validated and the level of approximation of the equations to be used in various cases is established. The formulation is then extended to smart thin-walled beams, mainly to bring out the phenomenological behaviour and to gain insight into the extent to which the response can be controlled. The effect of embedded actuators is considered implicitly in the evaluation of the elastic strain. Of the commonly used smart materials, piezoelectric and magnetostrictive materials are more popular as actuators. Relatively less amount of investigation has been carried out on the use of magnetostrictive materials for vibration suppression compared to piezoelectric materials. Hence, in the present investigation, the feasibility of vibration suppression in thin-walled beams with a layer of particulate magnetostrictive materials[6] embedded in the wall is studied.

3. Results and discussion

To illustrate the application of general equations, the flexural behaviour of a CFRP cantilever box-beam under tip load is considered. The theory yields analytical models of varying order of refinement depending on the level of approximation of the warp function. The well-known Euler–Bernoulli and Timoshenko's shear deformation theories can be obtained as subsets of the present theory. The bending slope under a tip bending load, predicted using three analytical models, Euler–Bernoulii (EB), shear deformation (SD) and the higher-order shear deformation (HSD), are correlated with the experimental data[7] available in the literature (Fig. 1). Good correlation is observed between theory and experiment. Studies are also made on the free vibration characteristics of rectangular box beams and I-beams and the results are compared with the available experimental data. The

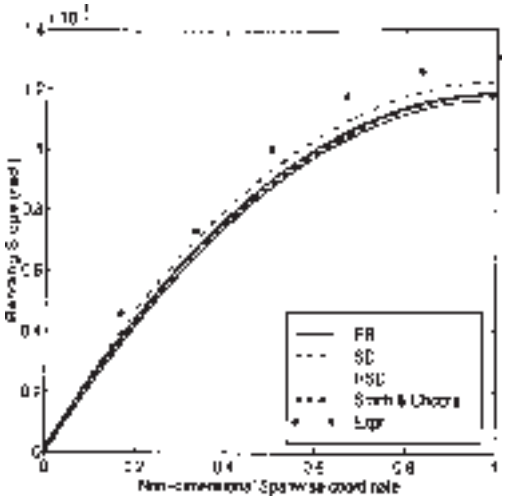

FIG. 1. Bending slope under tip bending load of 4.45 N for CUS090 layup.

correlation shows that the present approach is able to capture the static and dynamic behaviour fairly well.

The possibility of vibration control of smart thin-walled beams by embedding a layer of magnetostrictive material (Terfenol-D) in the walls of a CFRP box beam is then investigated.[2] The response of these beams in the first three modes is investigated using a constant gain and velocity proportional feedback control law. The results indicate the viability of developing thin-walled beams with embedded magnetostrictive layers with a vibration suppression capability, for applications such as helicopter rotor blades, aircraft wing spars, etc.

4. Conclusions

The focus of this work has been on developing a general theory for laminated composite thin-walled beams with smart features. The formulation is first applied for the static and dynamic

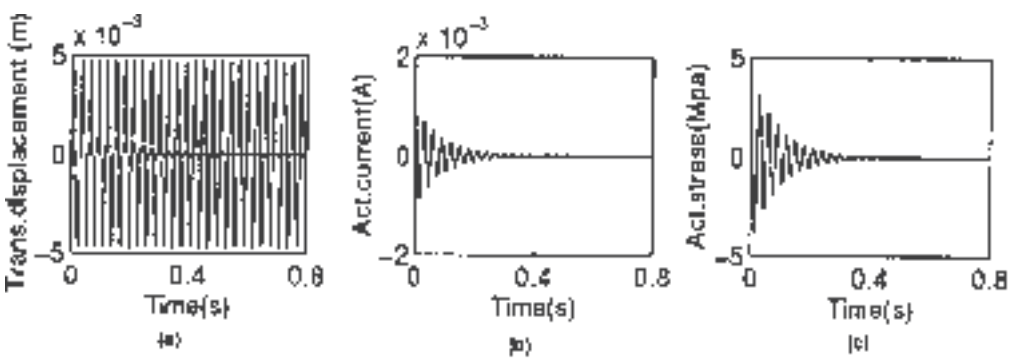

FIG. 2. Vibration suppression for fundamental mode of box beam 1, gain=10, ω_n = 210.25 rad/s. Variation of (a) mid-span displacement, (b) actuation current and (c) actuation stress.

analysis of laminated composite thin-walled beams without smart features to assess the performance. Then the feasibility of vibration suppression by embedding a layer of particulate magnetostrictive layer in the walls of the beam was investigated. Numerical studies were carried out on examples of rectangular box beams and I-beams. The results indicate that the present theory can serve as a suitable analytical tool for the analysis of laminated composite thin-walled beams with and without vibration control capabilities incorporated in them.

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Thesis Abstract (Ph. D.)

Design and evaluation of radar assisted collision avoidance/guidance strategies for low altitude flight by B. Ajith Kumar
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Department: Aerospace Engineering

1. Introduction

Obstacle avoidance is a fundamental requirement in the trajectory planning of aerospace vehicles.[1] Flight operations at low altitudes, especially those that are very close to the ground, have high work load and inherent risk. For military applications, operations at close proximity to the terrain are necessary to increase covertness and concealment. The pilot has to take quick and appropriate decisions to avoid collision with obstacles. Civilian applications such as surveying, surveillance, fire-fighting, agricultural spraying operations, etc. also require aerial vehicles to fly at low altitudes and consequently demand an effective collision avoidance system. The collision avoidance systems for aerospace vehicles that are in operational use today need expensive computations for real-time application. Thus, there is need to develop simple strategies, requiring comparatively fewer computations, for collision avoidance/guidance during low-altitude flight.

In this work we examine several radar-assisted collision avoidance/guidance strategies and discuss their merits and demerits. Based on some preliminary simulation results on these strategies we finally propose a novel collision avoidance strategy called radar-assisted collision avoidance/guidance strategy (RACAGS). The main advantage of RACAGS is its modest data and compu-

tational requirements, which makes it ideal for online real-time application as an effective pilot aid. It can also be used in unmanned aerial vehicles having effective lateral maneuvering capability.

We first introduce several important problems associated with the design of an effective collision avoidance system. Various features of the low-altitude flight regime that directly affect the collision avoidance task are discussed in detail. The notion of guidance is introduced as an important concept in the context of collision avoidance. Several robotic path-planning strategies, in particular the techniques based on artificial potential fields, are discussed. Major contributions appearing in the literature in these areas are also surveyed.

2. PN guidance approach for collision avoidance

We explore the possibility of modifying the popular proportional navigation (PN) guidance law, used extensively in the missile guidance literature, to obtain a collision avoidance/guidance strategy.[2] We design an avoidance law that generates a lateral acceleration command that is inversely proportional to the line-of-sight rate and is in the opposite direction to the guidance command. A few simple simulation runs illustrate that although this collision avoidance strategy is fairly effective in most cases, there are situations in which the strategy has severe drawbacks. For example, it tends to prescribe high lateral maneuvering commands even when the risk of collision is less. A qualitative separation of the avoidance and collision regions in the parameter space demonstrates the effect of maneuver level limits on the effectiveness of the PN-based collision avoidance strategy. Based on these results we abandon the PN approach to collision avoidance.

3. Potential field approach for collision avoidance

We then examine the possibility of using the artificial potential field (APF) technique in robotic path planning[3] to design a collision avoidance strategy for low-altitude flight vehicles. It is found that the APF technique cannot be directly applied to flight vehicles, mainly because of stringent restrictions on its forward speed, and requires some modifications. Even after these modifications, the simulation runs reveal that the resultant collision avoidance strategy fails to perform effectively in certain situations and thereby reveals a serious flaw in the strategy. Based on these results we abandon this approach.

4. Radar-assisted collision avoidance/guidance strategy for planar flight: The circular obstacles case

Next we present the radar-assisted collision avoidance/guidance strategy (RACAGS) which forms the main contribution of this work. The RACAGS algorithm is based on the range map and the cone of radar returns obtained from an active radar sensor. The maneuver command comprises two components, one each corresponding to avoidance and guidance maneuvers. An algorithm is designed to merge these commands in a logical manner. The strategy is initially applied to planar flight among circular obstacles. Several simulation runs were conducted to obtain collision-free trajectories under different initial conditions of encounter. The influence of the guidance cycle time is also shown. Simulation results presented for situations when the vehicle encounters multiple obstacles and moving obstacles show the viability of RACAGS and also demonstrate its ability to overcome the disadvantages the PN- and APF-based approaches.

5. Radar-assisted collision avoidance/guidance strategy for planar flight: The real-world environment

We then consider a real-world environment having obstacles of irregular shapes and sizes. A sliding circle algorithm is proposed to construct virtual obstacles as imaginary circles from the radar information. The vehicle maneuver command is derived with reference to these virtual obstacles using basic avoidance/guidance strategy. Several simulation runs show the effectiveness of the proposed strategy when the vehicle encounters single or multiple irregularly shaped obstacles during low-altitude planar flight. Results comparing the performance of certain path planning algorithms for robotic navigation with RACAGS presented show that the RACAGS trajectories are more suited to flight vehicles.

6. Radar-assisted collision avoidance/guidance strategy for planar flight: Nominal trajectory following

We next address the problem of intermediate goal following, waypoint following and nominal trajectory following. In waypoint following, the vehicle has to pass through a few intermediate goal points or subgoals while avoiding any collision with obstacles in its flight path. In certain other mission scenarios, the vehicle has to precisely follow a nominal trajectory defined by numerous subgoals. We design algorithms for both these cases to select subgoals efficiently and merge these algorithms with the basic RACAGS algorithm. Several simulation results of planar trajectories through single and multiple irregularly shaped obstacles illustrate the viability of using RACAGS for nomial trajectory following tasks.

7. Three-dimensional collision avoidance strategy

We next address the problem of a flight vehicle opting for contour flight or flight through a maneuver plane that is vertical or close to vertical and propose a strategy to select an inclined maneuver plane for avoiding obstacles of this type. Simulation results illustrate that the basic avoidance/guidance strategy can be used to maneuver around obstacles in three-dimensional space too and thus the basic RACAGS has application beyond the restrictive nap-of-the-earth flight.

8. Conclusions

The radar-assisted collision avoidance/guidance strategy designed here has the advantages of simplicity and real-time implementability. It also has the novelty of considering the tasks of guidance and avoidance together, which is a standard requirement in a real-life scenario. An important area of future extension of the work reported here would be in integrating these strategies with existing hardware to achieve increased autonomy. Some issues that can be addressed to improve the proposed strategy are also discussed.

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Thesis Abstract (Ph. D.)

Software quality and dependability issues for the airborne surveillance platform: A systems engineering study by B. Kanchana
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Department: Computer Science and Automation

1. Introduction

The airborne surveillance platform (ASP) is a complex software intensive system that is presently under development at the Defence Research and Development Organisation (DRDO). In this work, we study the quality and dependability issues connected with the real-time embedded software employed in the ASP. The issues of performance, quality, dependability and risk become important throughout the life cycle of the system. A methodology for understanding and managing these issues needs to be developed. In the early days (1970s and 1980s), the research focus in software engineering was on devising methods for efficient planning and control of software projects. The importance of software quality and dependability has only been recognised in the 1980s and this trend is continuing through the 1990s. It may, however, be noted that the quality issues have not received due attention in the context of large defence systems currently being developed in India. The project definition report (PDR) for the ASP only talks of "platform requirements having reasonably good performance in terms of endurance, range, cruise speed and safe flying qualities. For the HS 748 aircraft which is used as the platform for ASP project, the endurance is seven hours and thirty minutes".

To achieve total customer satisfaction with the ASP system, studies should necessarily include project and process based on measurements and metrics. This needs a comprehensive systems engineering approach to fully appreciate all the underlying issues in the design of ASP. The underlying premise is that large scale and complex software system development should be studied and modeled from more than a single perspective. A representative approach is the hierarchical holographic modeling (HHM) approach proposed by Chittister and Haimes.[1] Based on this approach for the ASP software dependability, we can employ the following perspectives: the software development perspective, the environment perspective and the quality perspective. *Software development perspective* addresses issues within requirements, specification, architecture, process, testing, product and support systems for integration. *Environment perspective* addresses hardware failure, organisational failure, human failure and failure due to sources external to the system. *Quality perspective* addresses the technical performance of the product, cost overrun and time delay in schedule. These three perspectives comprehensively identify all software dependability issues.

A goal of this study is to investigate organisation needs for quality assessment, to determine the errors, and effort data to be collected in this environment for addressing quality assessment needs. Goal/question/metric (GQM) paradigm is used for defining and quantifying quality assurance and improvement goals of organisational interest. The GQM approach is aimed at supporting measurement goals. Its advantages are its general applicability and support for defining goals and refining them into questions and metrics. It can be used for quality management of any process or product as well as project management. Other advantages are support for identifying and tailoring metrics, support for interpreting measurement data, support for early validation of metrics, support

for evolving all interested parties into the measurement process and support for protecting sensitive data. This work tries to establish the organisational quality goals by answering certain important questions such as:

–Are statistics on software design errors gathered?
–Are statistics on software code and test gathered?
–Are design errors projected and compared with errors located?
–Are design and testing optimisation techniques available?
–What is the current reliability?
–What is the plan to improve maturity?

It is well known that quality issues can be considered at two levels—the intrinsic product quality and total customer satisfaction.[2] For the ASP software, the product quality is recognized as a lack of 'bugs' or design defects in the software.

2. Experimental

In the first part of this work, we attempt to specify a product dependability requirement based on the PDR. This translates into an availability requirement that the software system should be 'available' throughout the mission duration, which may be 5 to 6 h. This is seen to be a metric only related to the software product that is being developed. As a first step in quantifying the dependability of the real-time software used in ASP, a defect data collection technique is developed. This technique involves program instrumentation, i.e. to insert additional statements into program under test for the purpose of collecting and computing certain program attributes. This technique also avoids the need for producing stubs. The test input data, test result, time of failure, phase of life cycle and date of test are recorded, whenever a defect is found.

From the *environment perspective* reliability estimation of the ASP software is carried out using the defect data collected. When analysing the test data as a stochastic point process, it is important to determine whether the process has a trend, i.e. to know whether the failure rate is increasing, decreasing or constant to apply an appropriate model for reliability estimation. It has been observed that the trend is negative which indicates reliability growth, i.e. the inter-arrival times of errors are tending to become larger. Reliability growth model such as the basic model and the logarithmic Poisson model (LP) are applied and compared. Although software reliability models are still in experimental stage, they can be used to provide reasonable predictions of the number of defects remaining, which is an indicator of whether the software is ready for release for the ASP flight trails. Experience has shown that predictions from both the basic model and the logarithmic Poisson models of defect occurrence times correlate reasonably well with field data.

The complexity of software often affects its reliability. In order to produce reliable software, its complexity must be controlled by suitably decomposing the software system into smaller subsystems. In this work, from the *software development perspective* a complexity metric is developed which allows analysing the software during the development and provides a means to revise the architecture design by further decomposing the module. A software tool based on the design metric is developed to identify the critical modules for software development for iRMX environment. This tool accepts the iRMX code and outputs the list of critical and noncritical modules. The critical modules need to undergo both white and black box testing. Hence the

organisation allocates more test time for these critical modules. The product metric introduced in this work, results from a study trying to introduce sound measurement and evaluation procedures into a defence software development environment.

In order to address the *quality perspective* of software development process, the applicability and relevance of Taguchi methods to engineer quality and performance into new software products and software process are attempted in the second part of the work. A technique that reduces variation by reducing the sensitivity of an engineering design to the sources of variation rather than by controlling these sources is called parameter design.[2] Let the product or process under study be referred to as a system into (a) 'control factors' $\boldsymbol{x}$ that can be easily controlled and manipulated and (b) 'noise factor' $\boldsymbol{z}$ that is difficult or expensive to control. Variation in $\boldsymbol{z}$ during manufacturing or operation causes variation in the system's performance measured by some quality characteristics $\boldsymbol{y}$. There could be many settings of $\boldsymbol{x}$ at which the system can perform, on an average, at desired levels. Taguchi has proposed a collection of techniques to identify the settings of $\boldsymbol{x}$ that would achieve robust performance. These include statistical experimental design and analysis techniques. These control parameters $\boldsymbol{x}$ are varied according to an orthogonal array. At each setting of the control factors, the effects of the noise factors are evaluated by varying them systematically using a noise array. Taguchi also classifies parameter design problems into different categories and defines a performance measure, which he calls 'signal-to-noise' ratio, for each category. The estimated signal-to-noise ratio is analysed to identify the control factors that will yield robust performance. As a check for the assumptions that are in his approach, Taguchi recommends conducting one or more runs at the predicted settings to verify that the predicted performance is in fact realised.

The objective of design of experiments is to conduct offline experiments using orthogonal arrays. Towards this, the cause–effect diagram captures the causes for the number of defects introduced in the design phase. From this diagram we identify the three most likely parameters for possible causes for introducing software design error; as the coupling, the number of requirements per module and McCabe's cyclomatic complexity. These parameters are broken down into either two or three levels. McCabe's cyclomatic complexity and the number of requirements are set at three levels and the coupling at two levels. The possible number of factorial experiments required to be conducted for the levels selected for the three parameter is $2*3*3=18$. The appropriate orthogonal array based on the guidelines of Taguchi is L_9. That is, nine experiments need to be conducted to find the optimal software design parameters. On an average three different modules were tested for each of the nine experiments. To seek robustness one should measure the performance by signal-to-noise ratios. After the analysis on signal-to-noise ratio we could arrive at the optimal parameters for the software design process. They are a very low number of requirements per module, high coupling and the McCabe's complexity of less than 10. The result obtained confirms the ordinary software practices. This method can be applied at any radial dimension of the spiral model of the software life cycle for process improvement.

Software testing involves a review of the specifications, design and coding of the package/ program, and is therefore a critical element of software quality assurance. Besides, testing reveals the degree to which the software conforms to the performance requirements spelt out by original specifications. Test data, in short, are a good measure of software reliability, i.e. of how well or ill it will stand up to the demands of practical applications. The Taguchi framework is a testing technique

that applies the optimum white and black box combination to the modules identified by the design metric as crucial. Black box testing applies to equivalence classes and boundary value analysis, and white box testing to basis paths and loops. The optimal combination of testing techniques obtained is that of equivalence class partition and basis path testing. This is confirmed by conducting tests on three different modules.

3. Conclusion

This work presents a systems engineering study pertaining to the software quality assurance of the ASP project. It is shown that the HHM framework provides a comprehensive methodology for studying the software quality and reliability perspective, which is one of the perspectives of the HHM framework. A defect data collection technique was evolved and the reliability estimation was carried out on this defect data. A real-time design metric is developed to identify critical modules. Finally, Taguchi methods are shown to be useful for software development process optimization.

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Thesis Abstract (M.Sc.(Engng))

Evaluation of the stress intensity factors for two- and three-dimensional crack problems using universal crack closure integral by Adris Bisi
Research supervisor: Prof. B. Dattaguru
Department: Aerospace Engineering

1. Introduction

Design procedures based on linear elastic fracture mechanics (LEFM) are found to be adequate for practical crack problems involving small scale yielding (SSY) around the crack tip. Over the last two–three decades extensive work has been done to evaluate the required fracture parameters such as strain energy release rate (G) components and stress intensity factors (K) in various modes of fracture based on LEFM by post-processing stress and displacement output from FEM analysis of cracked structural components. The concept of Irwin's crack closure integral (CCI) has been extensively exploited for this purpose in combination with FEM in forms known as virtual (or modified) crack closure integral. In such procedures, however, the expressions for components of G are element dependent and need to be derived whenever a new element is employed in FEM analysis. In this work, a new procedure called universal crack closure integral (UCCI) is proposed to overcome this limitation.

2. Contributions of the thesis

An UCCI can be thought of as a numerical integration procedure wherein a product of stresses ahead of the crack tip and the displacements behind the crack tip are integrated to obtain strain energy release rate (G) components and the corresponding stress intensity factors (SIF).

An attempt is made initially to develop the numerical integration procedure with the objective of minimizing the numerical errors introduced during SIF estimation. We consider the problem of a central straight crack in an infinite plate under uniaxial tension with the exact closed form solution describing its stress and displacement fields. For numerical integration, Gauss quadrature method is carried out over a certain length across the crack tip by dividing the full integration domain with different number of subdivisions and applying different Gauss point rule. By avoiding both the generally erroneous zone in the vicinity of crack tip/front where stress singularity occurs and also the region far away from crack tip/front where the stresses and displacements are not dominated by K, we search for an accurate numerical integration scheme (in particular, integration domain) for the estimation of K. During this work, the concept of mid-fractional domain integration is found to be quite effective in alleviating errors due to integration.

The UCCI procedure is later employed to postprocess FE solution for stresses and displacements to extract SERR components and SIFs for various crack problems in finite domains. Numerical studies are carried out on both two- and three-dimensional problems to compare the results obtained by the present procedure with the results from standard reference solutions.

The following problems are analyzed in two dimensions:

(i) Center crack tension (CCT) specimen (Mode-I) (Fig. 1a);
(ii) Single edge crack (SEC) tension specimen (Mode-I) (Fig. 1b); and
(iii) Mixed-mode problem of inclined crack in tension specimen (Modes-I and II).

In the first two cases, a parametric study is carried out on the choice of virtual crack extension ($\Delta a/a$) so that the errors from UCCI procedure are within 1–2% compared to reference solutions. For this purpose, we have taken three different crack lengths in each of the problems of center and edge cracks. It is found that choice of 10–20% for $\Delta a/a$ provided accurate solutions in all the problems considered. Here the numerical results for Mode-I fracture in CCT and SEC specimens are presented in Table I where FEM employed 8-noded quadrilateral elements.

Also it is seen that UCCI can be effectively used to estimate components of G in individual modes (G_I, G_{II}) for the problem of mixed mode fracture (Table II).

Table I
Comparison of the present UCCI SIF ($K_I/\sigma\sqrt{\pi a}$) estimates with the values of Broek[1] for CCT and SEC specimens with a/w = 0.1
(Ref. solution: $K_I/\sigma\sqrt{\pi a}$ =1.0062 for CCT and =11864 for SEC specimen)

Specimen	$\frac{\Delta a}{a}$ = 30%	$\frac{\Delta a}{a}$ = 25%	$\frac{\Delta a}{a}$ = 20%	$\frac{\Delta a}{a}$ = 15%	$\frac{\Delta a}{a}$ = 10%	$\frac{\Delta a}{a}$ = 5%
CCT	1.0288	1.0207	1.0191	1.0112	1.0030	0.9866
(% error)	(2.20)	(1.42)	(1.27)	(0.50)	(–0.32)	(–1.99)
CCT	1.2044	1.1959	1.1957	1.1883	1.1804	1.1633
(% error)	(1.49)	(0.79)	(0.78)	(0.16)	(–0.51)	(–1.99)

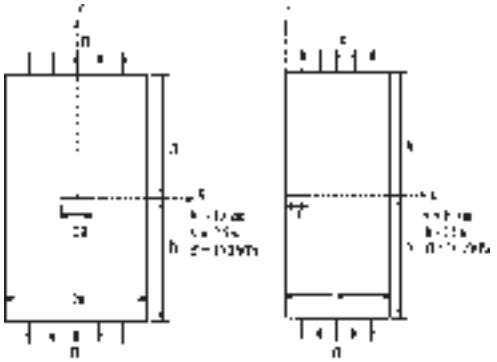

FIG. 1. Two-dimensional specimens with crack.

Table II
Comparison of the present UCCI SIF ($K_I/\sigma\sqrt{\pi a}$, $K_{II}/\sigma\sqrt{\pi a}$) estimates with the values of Badari Narayana[2] for inclined crack

Mode of fracture	Ref. SIF	UCCI SIF	% error
Mode-I	0.5	0.5004	0.10
Mode-II	0.5	0.5025	0.52

Three-dimensional problems with straight and curved crack fronts are analyzed keeping the choice of $\Delta a/a$ within the range established in 2D problems. The following problems are analyzed:

(i) Through crack in thick slab under remote tension;
(ii) Embedded penny-shaped crack in thick slab with remote tension; and
(iii) Embedded elliptical crack in thick slab under remote tension.

In both through crack in a thick slab and embedded penny-shaped crack in a thick slab, excellent results are obtained (within 2% of reference solutions) for the stress intensity factor variation along the crack front. Results for through crack are shown in Fig. 2. The results for elliptic crack are within 3–4% of the reference solutions (Fig. 3). This is partly attributed to the fact that the FE mesh used did not have virtual crack extension perpendicular to the crack front.

3. Conclusion

The present work establishes UCCI as a viable procedure for postprocessing strain energy release rate components and to extract stress intensity factors in individual and mixed-mode crack problems

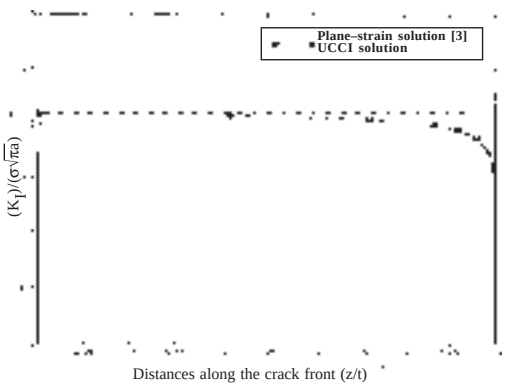

FIG. 2. Variation of the SIF (K_I) along crack front for the single-edge crack problem (z/t=0–middle plane, z/t = 0.5–free surface).

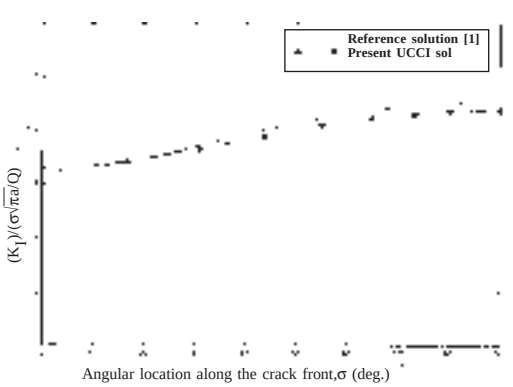

FIG. 3. Variation of the SIF (K_I) along crack front for the elliptical crack.

in two- and three-dimensional fields. It serves the objective of overcoming the limitation of element-dependent MVCCI expressions and so can easily serve as a stand-alone module to any stress analysis package.

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Thesis Abstract (M.Sc. (Engng))

Development of a general-purpose Sanskrit parser by P. Ramanujam
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Department: Computer Science and Automation

1. Introduction

In this work, we present the development of a general-purpose parser for Sanskrit, which generates a parse tree for a given sentence if it can be derived from the grammar. We utilise various aspects of the language like syntax, semantics and pragmatics integrally. An algorithm for plain as well as accented input morphological analysis is developed and a working program designed using it. Algorithm for sentence analysis at syntactic and semantic levels is also attempted. Necessary input and display environments are evolved for accented inputs as an addition to standard representation.

2. Morphological analysis

The problem is addressed at word and sentence levels currently. Plain and accented inputs are considered (to cater to classical as well as Vedic Sanskrit). Word-level extracts and word-category information are based on Panini's rules. These include accent-related rules.

2.1. *Word structure classification*

A word can be denoted as follows:

W = B + T, where W represents a word, B the nucleus of a word and can take variety of forms depending on the type, and T the terminal suffix (either nominal declensional suffix or verbal conjugational suffix).

Depending on what form B and T take, the words can be classified into different types.

According to Panini, there are only two basic syntactic types of words, depending on the forms T takes. They are: i) Nouns or nominals: Here the terminal suffix T is a nominal suffix. ii) Verbs: Here the terminal suffix T is a verbal suffix.

But based on the form the nucleus of a word takes, the words in Sanskrit can be classified into two types as follows: i) Noncompound words and ii) Compound words.

The nucleus of a word B may consist of one or more nominal bases (Pratipadika-s), one or more Krt suffixes, one or more taddhita suffixes, a feminine suffix, a verbal root, one or more upasargas, etc. (i.e. the categories of compound and noncompound words are present in both nouns and verbs.) Words which contain only one nominal base with zero or more suffixes (non-vibhakti), one verbal root with zero or more suffixes (nonterminal) along with terminal suffixes are termed as *Non-compound* words. Words which contain more than one nominal base, one or more upasarga-s along with a verbal root, etc. are termed as *compound* words. These may further be *accented* or *plain*.

3. Accented input analysis

Accented inputs are handled using Vedic grammar rules in addition to Panini's rules, particularly in sandhi, determining unique identification in multiple parse cases and meaning determination. Accents as semantic category denoters are helpful in this process.

3.1. *Heuristic procedure*

(A) Samhita to Padapatha - StoP Algorithm

1) convert svarita and pracaya-s to anudatta,
2) Expand I' gya-s, add iti and rewrite separately,
3) With udatta-s as pivot, accent each syllable,
4) If there are any jatya (nitya) svarita-s, write it as it is,
5) Undo any sandhis in samhita (prose) form and write pausa form cerebralization/elongation non-sandhi, etc.
6) Other specialities of pada-patha to be added, Itiga-s.

(B) Pada patha to samhita PtoS algorithm

1) dissolve all special features of pada-patha,
2) make anudatta-s all svarita-s and pracaya,
3) combine words make sandhi euphonically as per rule base,
4) making udatta-s fixed, complete accent marking,
5) hrasva/dirgha kampa-s are to be placed appropriately,
6) carry out elongation cerebralization, etc.

3.2. *Algorithm*

After taking care of accent information if input is accented, and directly otherwise, we can adopt the following general strategy:

1. **Take** a Sanskrit word input.
2. **Check** whether the word is an avyaya (indeclinable). If so, store the identification.
3. **Check** whether the word is any special form. If so, store the identification.
4. **Generate** all possible splits of a word (along with second-level character substitution) giving rise to different substring combinations.
5. **For** all substring combinations

do

6. **Check** the last substring in the nominal and verbal suffix databases.
7. **if the last substring is a nominal suffix**

   then
8. **While** there are more substrings in the combination

   do
9. **Take** the next substring.
10. **Check** the substring in the following databases in turn

    i) Krt suffix, ii) Taddhita suffix, iii) Feminine suffix, iv) Nominal base, v) Verbal root, and vi) Upasarga.

    If a match is found in any of the databases, carry out a compatibility type **check** between the corresponding substrings, **and if** OK, store the identification along with the relevant details of the substring in the combination.
11. **if** the substring does not match in any of the databases, **break** out of the **while** loop;
12. **if** the total identification of all the substrings of the combination is such that it is one of the valid word structures **then** store the total identification of the word.
13. **Else if the last substring is a verbal suffix**

    then
14. **While** there are more substrings in the combination

    do
15. **Take** the next substring.
16. **Check** the substring in the following databases in turn.

    i) Modal suffix, ii) Conjugational suffix, iii) Various augments, iv) Verbal roots and v) Upasarga.

    if a match is found in any of the databases, carry out a compatibility type **check** between the corresponding substrings, **and if** OK store the identification along with the relevant details of the substring in combination.
17. **if** the substring does not match in any of the databases, **break** out of the **while** loop;
18. **If** the total identification of all the substrings of the combination is such that it is one of the valid word structures, **then** store the total identification of the word.
19. **Else**
20. **Take** the last substring.
21. **While** there are more substrings in the combination

    do
22. **Check** the substring in the avyaya list, **if** a match is found, store the identification, **take** the next substring and **continue**.

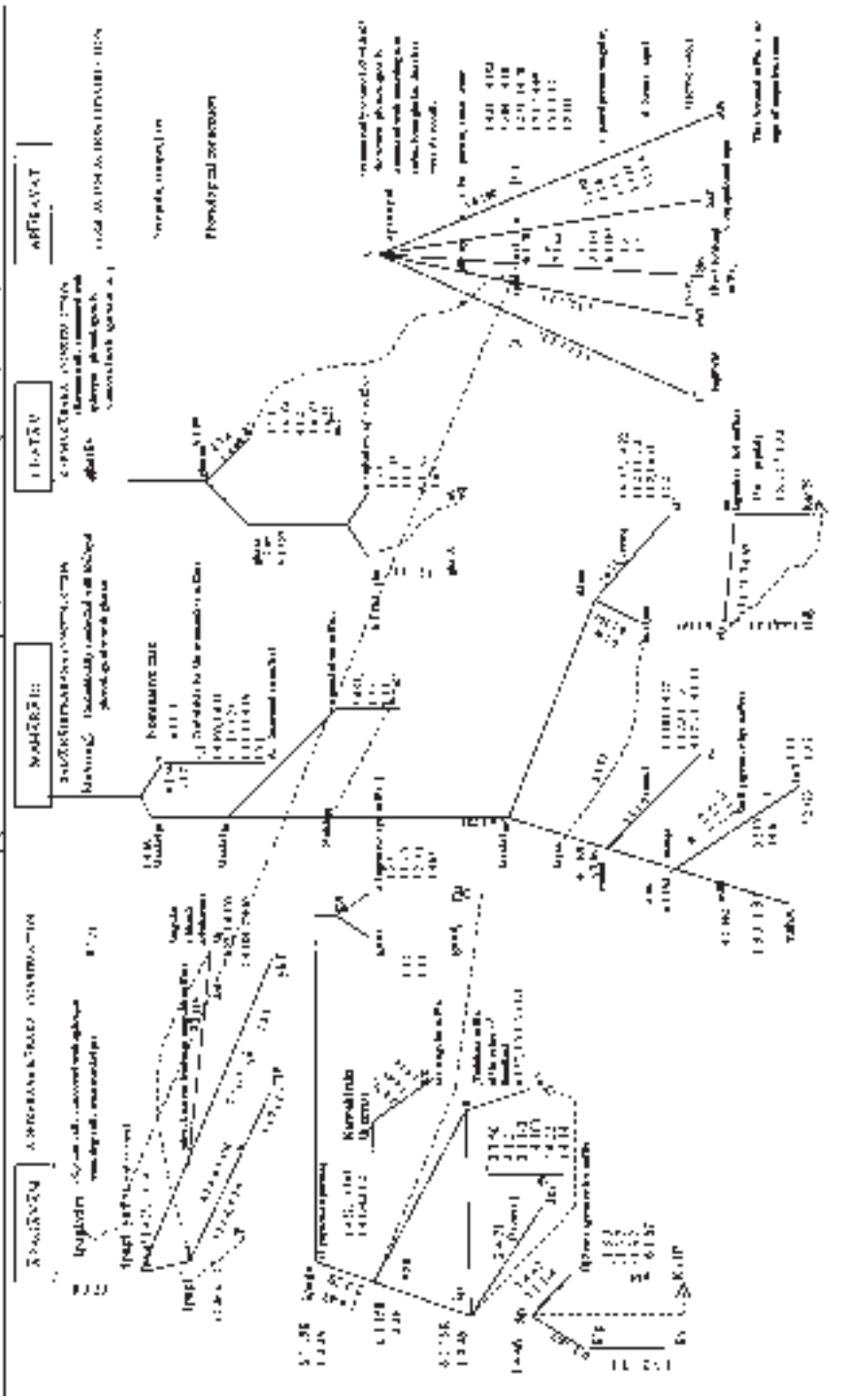

FIG. 1. Parse tree showing word analysis-through Paninian derivations with rulebase references.

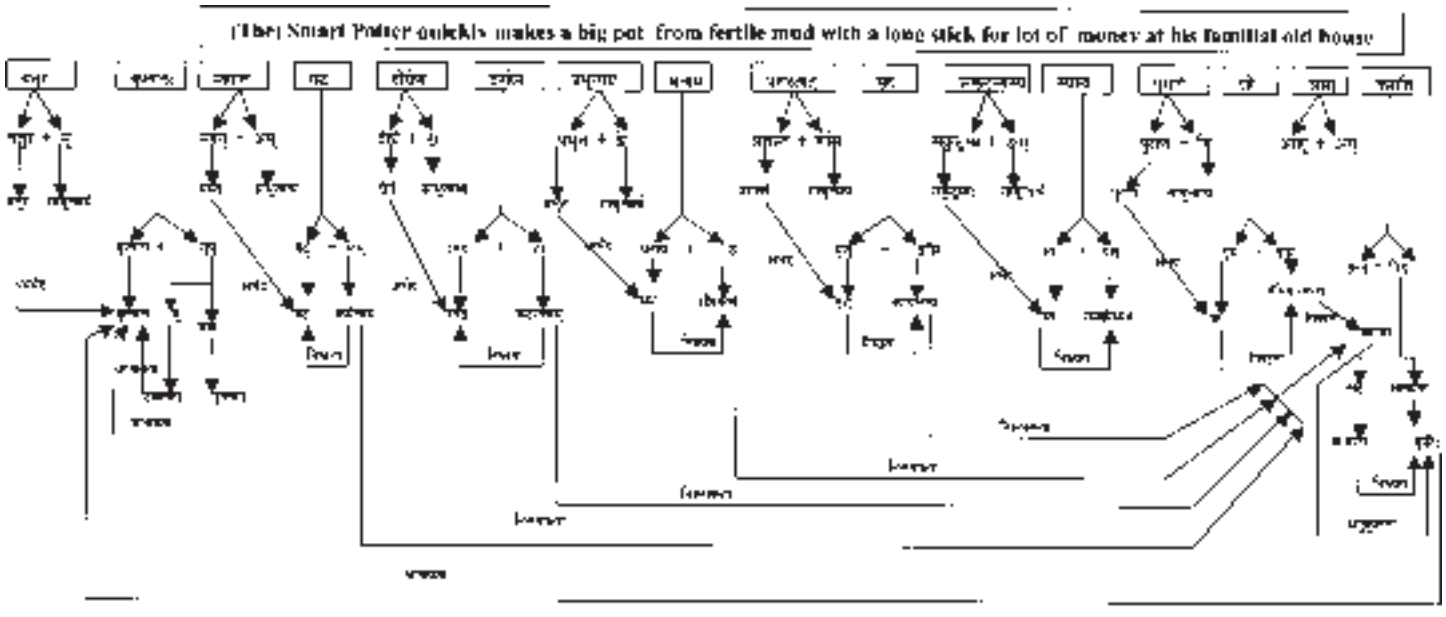
(The) Smart Potter quickly makes a big pot from fertile mud with a long stick for lot of money at his familial old house
शाब्दबोधः - महदभिन्न-घटनिष्ठकर्मतानिरूपक-दीर्घाभिन्नदण्डनिष्ठकरणतानिरूपक-प्रभूताभिन्नधननिष्ठोद्देश्यतानिरूपक-प्रशस्ताभिन्न-मृन्निष्ठोपादानतानिरूपक-सकुटुम्बाभिन्न-स्वनिष्ठसम्बन्धितानिरूपक-पुराणभिन्नगृहनिष्ठाधिकरणतानिरूपक-आत्मभिन्न-व्यापारानुकूल-वर्तमानकालनिष्ठ-कृत्याश्रयः एकत्वाश्रयः पुंस्त्वाश्रयः चतुराभिन्न-कुलपतिः ।
Nayāyika-Śābda-bodhaḥ - Aśrama-staraḥ - Saviśeṣaṇa-Sarvakāraka-Sasambandha-kriyā-Pada-yutaḥ - Viśiṣṭa-Bodhaḥ

FIG. 2.

23. **Check** the substring in the following databases in turn.

    i) Krt suffix, ii) Taddhita suffix, iii) Feminine suffix, iv) Nominal base, v) Verbal root and vi) Upasarga.

    if a match is found in any of the databases carry out a compatibility type **check** between the corresponding substrings, **and if** OK, store the identification along with the relevant details of the substring in combination.

24. **if** the substring does not match in any of the databases, **break** out of the **while** loop;

25. **If** the total identification of all the substrings of the combination is such that it is one of the valid word structures, **then** store the total identification of the word.

26. **If** there is no identification for the word (for any of the substring combination), **then print** the word is not a valid Sanskrit word; **else print** all the grammatical identifications of the word.

27. **END**.

4. Sentence analysis

At sentence level, grammatical analysis follows an expectancy-based approach. This process is traditionally termed as '*Shabda-bodha*'. Constraints and mappings between case-markers and case-relations are used. Words are grouped into source and demand words. A unique assignment of words of the input sentence is aimed at. Sentence-level parsing generates a paraphrase of the input sentence in many forms. Multiple parses and inadequacies may get highlighted in different cases where additional procedures are called for disambiguation.

5. Sample outputs

For Parse tree, see Fig. 1 and for shabda-bodha, see Fig. 2.

6. Conclusions

An attempt has been made to survey the contents of Indian technical treatises on language comprehension and adapt them for NLP research work. Necessary extensions to information interchange standards have been evolved and computer interfaces through Indian scripts (covering Vedic texts also) are devised.

A preliminary algorithm has been designed for morphological analysis for classical and Vedic Sanskrit. Necessary databases are also built (and a trial implementation has been achieved). The Vedic extension rulebases are testable against the Vedic databases built. A Parser with syntactic and semantic processing provisions and ontological knowledgebase is designed.

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Thesis Abstract (M. Sc. (Engng))

Performance evaluation of backbone technologies in distributed systems by M. Rajiv
Research supervisor: Prof. D. K. Subramanian
Department: Computer Science and Automation

1. Introduction

The *communication network* in a distributed system is a crucial subsystem within a distributed system as it is the foundation on which the distributed computing paradigm rests. Switched networks are becoming popular today as they increase many fold the available bandwidth for each application as compared to the older shared networks.

The backbone of a switched network is the area where network traffic from different sources aggregate, especially when the routes to file servers span the backbone. Thus, the backbone of the network is a potential bottleneck point. Today, in the context of the controversy about the best backbone, we evaluate fast ethernet, gigabit ethernet and ATM as backbone technologies.

Previous studies such as Vingralek *et al*.[1] have concentrated on load balancing with dynamic data migration on a cluster of WWW servers. In Elsaadany *et al*.[2] and Raju and Mittal,[3] the focus is on switch architectural requirements.

2. Framework and methodology

2.1. *Framework*

We have evaluated the performance of the backbone of a distributed system using different interconnection technologies and the effect of reconfiguration of the backbone on overall performance of the system.

In the present simulation study, we have used a real-life network traffic model[4] and consider a client-server model of a distributed system where the end-points of the network are client machines and file servers. The network consists of hubs, high- and low-speed switches and network links.

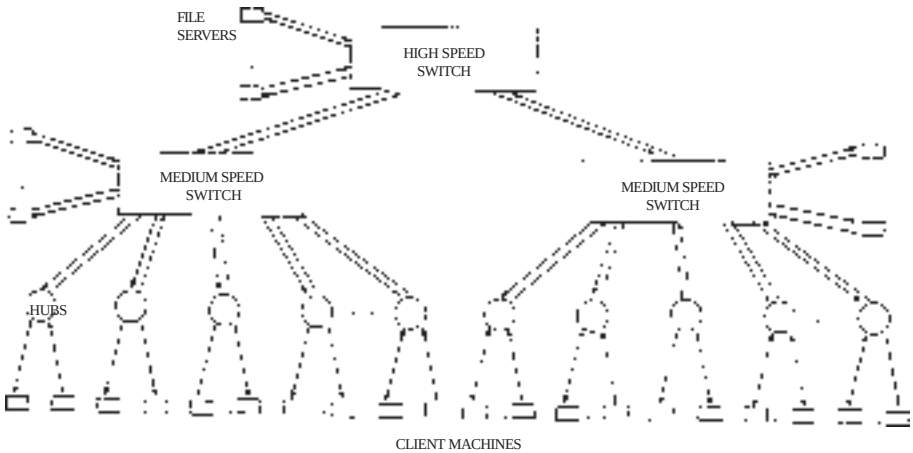

FIG.1. Network topology.

Detailed queueing models of these components have been used in the simulation study.The topology we have used for our simulation experiments is shown in Fig. 1. The switch architecture used is that of an industry-standard switch. In the network that we considered, there were 100 client machines, 20 file-servers, 10 hubs, two medium-speed switches and one high-speed switch.

The output parameters are *message response time* and its *standard deviation, message queue lengths* at the client, *utilization of links* and the associated *switch delays* and *switch queue lengths.*

2.2. *Methodology*

A detailed simulation study was carried out to evaluate the above-mentioned system. The study employed the simulation library C++ SIM. Several models were developed as part of the modeling exercise, which included a job model, machine model, the ethernet CSMA/CD model, a detailed switch architecture model and a realistic traffic model. A module was also developed which read in the topology of the network from an input file and generated the routing table. Since running time of the simulation was seen to be very high, we added several optimizations to the simulator in order to make it run faster.

3. Major findings

We have evaluated the system with fast ethernet, gigabit ethernet and ATM backbones. We used the ATM UBR (unspecified bit rate) service for implementing the ATM backbone. The comparative performance of these systems for the message response time metric is shown in Fig. 2.

It was seen that in the same configuration, the fast ethernet backbone performed rather poorly in comparison. It was seen that for a fast ethernet system the high-speed switch at the root of the topology was becoming a bottleneck due to low output link speed whereas in the gigabit ethernet and ATM backbones, the medium-speed switches were seen to be the bottlenecks due to the low speed hub to medium-speed switch link.

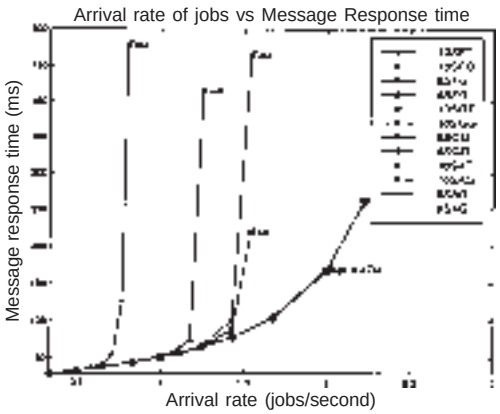

FIG. 2. Average message response time.

We decided that if we could load the switches in the backbone uniformly, we may be able to achieve better response times in the fast ethernet backbone. Therefore, we have evaluated the performance with interconnecting the medium-speed switches and shifting the file servers around the switches. The results by interconnecting the medium-speed switches showed that response time for the fast-ethernet backbone has improved substantially. We then shifted the file servers around the switches to observe the changes to the response time. Response time again showed improvement up to a point after which performance actually started degrading. The interconnection of medium-speed switches did not affect the performance of the system with gigabit ethernet and ATM backbones as the bottlenecks were no longer the backbone links; rather, they were the switch-to-hub links.

From the simulation results it is clear that by simply reconfiguring an existing fast-ethernet backbone, we can achieve much better performance. The gigabit ethernet backbone clearly outperformed the fast-ethernet backbone, but by uniformly distributing load on the backbone, we could achieve better performance in the fast-ethernet backbone which was quite close to that of gigabit ethernet.

We also found that gigabit ethernet and ATM backbones performed equally well. In both the backbone configurations, the switch-to-hub links were becoming the bottlenecks. Different behaviour may be observed if the bandwidth of the switch-to-hub links is increased. This and incorporation of TCP flow control schemes and ATM QoS such as CBR, VBR, ABR, etc. may be carried out as part of the future work.

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Thesis Abstract (M. Sc. (Engng))

TriSL: A software architecture description language and environment by R. Lakshminarayanan
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1. Motivation

As the size and complexity of a software system increases, the design problem goes beyond the algorithms and data structures of the computation: designing and specifying the overall system structure emerges as a new kind of problem. Structural issues include gross organization and global control structure; protocols for communication; synchronization and data access; assignment of functionality to design elements; physical distribution; composition of design elements; scaling and performance; and selection among design alternatives.

Getting the right architecture is often crucial to the success of a software system design; the wrong one can lead to disastrous results. Detailed understanding of software architectures allows the engineer to make principled choices among design alternatives. An architectural system representation is often essential to the analysis and description of high-level properties of a complex system. This creates the need for a formal notation for representing and analyzing architectural designs. That is precisely what TriSL is.

2. Problems with state of the art

Unfortunately, with few exceptions, current exploitation of software architecture and architectural style is informal and ad hoc. While architectural concepts are exploited in infrastructure to support architectural styles and in the initial conceptualization of a system configuration, the lack of an explicit, independent characterization of architecture and architectural style significantly limits the extent to which software architecture can be exploited using current practices.

- *Box and line diagrams*: Currently, architectural configurations are typically described using informal *box and line* diagrams in design documentation, providing little information about the actual computations represented by boxes, their interfaces, or the nature of the interactions between them (represented by lines).

- *No abstract definition of interactions*: Currently, the abstract behaviour of the components and their interactions are not explicitly defined, and hence analysis cannot be carried out at an abstract level. When component interactions are, at most, informally specified, it is also more difficult to reuse high-level design effort in other systems.

- *Informal and ad-hoc approaches to architectural style*: Current approaches to architectural style are also informal and ad hoc. This lack of precise characterization means that communicating the meaning of the style to others is difficult. Further, the lack of a precise formal basis for style also limits the analytic leverage of a style.

3. Architecture description languages

Architecture description language (ADLs) result from a linguistic approach to the formal representation of architectures, and as such they address the shortcomings of informal (box-and-line) representations. Further, sophisticated ADLs allow for early analysis and feasibility testing of architectural design decisions.

A number of ADLs have been proposed for modelling architectures both within a particular domain and as general-purpose architecture modelling languages. To list a few: Darwin,[1,2] Rapide,[3] Unicon,[4] WRIGHT.[5] Recently, initial work has been done on an architecture interchange language, ACME,[6] which is intended to support mapping of architectural specifications from one ADL to another, and hence enable integration of support tools across ADLs.

TriSL differs considerably from the current ADLs in many aspects and provides constructs of building software architecture, not just specifying it.

4. TriSL

The primary purpose of TriSL is to provide a set of constructs that will aid an architect in incremental development and specification of the overall structure of a software system. TriSL should make it possible to capture the structural information of a software system and specify it in a reusable form. TriSL provides a coherent core based on the incremental development model which allows the architect to build software architectures.

4.1. *Basic building blocks*

The architectural elements, components and ports, connectors and roles form the basic building blocks for software architecture description. A configuration of these architectural elements is called a system. TriSL provides constructs to specify all these basic building blocks. In TriSL every architectural element has a type. These building blocks are instances of their corresponding types. TriSL makes a clear distinction between architectural element types and their instances. This distinction is central to the support for reusability of architectural descriptions. Much of the semantics of an architectural element is represented by its features, defined as its properties. Properties in TriSL are *typed name-value pairs.*

4.2. *Architectural element type*

Architectural element type is an important notion in TriSL. It forms the core on which a lot of the features provided by TriSL depend upon. Specifying architectural elements as type hierarchies is a domain-independent approach that structures relationships between software components and enables us to verify those relationships via type checking. TriSL supports definition of component types, connector types, port types and role types. TriSL also supports capturing reusable architectural patterns as styles. Architectural styles can be viewed as a system of types, where the architectural vocabulary be defined as a set of types. Vocabulary types and rules provide mechanisms for capturing and encapsulating design expertise in the form of design vocabulary and constraints.

The important feature that distinguishes TriSL and other ADLs is its type system. The TriSL type system is based on structural type equivalence, i.e. two types are equivalent if they have the

same structure. The type system also supports structural subtyping. Subtypes provide a very flexible extension mechanism that allows architects to extend and reuse existing types. The TriSL type system does not require subtyping relationship to be specified explicity, it infers the relationship. This feature is very important for an ADL that supports incremental and interactive development.

In TriSL, types can be parameterized with type variables. Type variables allow the architect to defend generic types. Further, type variables can also be used to express type dependencies. For example, a connector type can define its input and output to be of the same type variable. Styles can also be parameterized.

TriSL supports mutable types and instances. To support incremental development model, TriSL makes the distinction of mutable and immutable names. Mutable types and instances provide flexibility and incremental developmental model required by external tools that manipulate architectural descriptions.

4.3. *Constraints*

Constraints specify heuristics, invariants, composition constraints and contextural cues to assist architects with the design and analysis of software architectures. TriSL allows specification of constraints in style and type definitions. Types may specify constraints that preserve the structure defined by them. Structures, instances of these types, are modified or manipulated through operations like adding a structure to another structure as a substructure (for example, adding a port to a component) or deleting a substructure from a structure (for example, deleting a port from a component). Types can also specify constraints on composition of themselves with other elements. Instances of types are composed through operation like attaching a structure to another structure (for example, attaching a port to a role), detaching a connection (for example, detaching a port from a role), binding representations with their parent and unbinding representations from their parent. TriSL allows an architect to attach constraints to any of the operations on structures.

This feature distinguishes TriSL from other ADLs which provide a single form of constraint, which is checked on all operations. This approach of explicit and operation-specific constraints has two advantages. First, it gives the architect a finer granularity of constraint specification. Second, only the constraints related to the operation performed need to be checked. The second advantage saves a lot of computational time from implementation point of view.

Constraints can exploit the subtyping feature, by specifying polymorphic operands. Constraints when combined with parameterized types provide an elegant way of expressing constrained genericity. These two features, polymorphic operands in constraints and constrained genericity, add to the power and expressiveness of TriSL.

4.4. *Specification versus building*

Software architecure development is inherently incremental and interactive in nature. Current ADLs are based on the static specification model. We envision an ADL that is different from this traditional approach and supports building of an architecture, not just specifying it. TriSL has the incremental interactive development as its underlying model.

5. Formal definition of TriSL

We formally specify the type system of TriSL through type rules. The semantics of the constructs of TriSL is formally specified using operational semantics. The lexical structure of TriSL is also presented.

6. Design and implementation

We have modelled the system using object-oriented methodology and implemented the system using C++. We have also developed a graphical front-end, TriSL work-bench, through which the features provided by TriSL can be easily accessed. We have implemented the work-bench using the Qt GUI toolkit.

7. Case studies

We demonstrate the power of TriSL through two case studies. We show how the various control architectures for automated manufacturing systems (AMS) can be formalized using TriSL. We then formalize the architecture of the AMS designed for Widia India Limited, using TriSL, and discuss the advantages. The second case study presents a classic case of the problems faced by designers and programmers due to change in the structure of a framework, the migration from Java 1.0 event model to Java 1.2 event model. We present both the models, and show how the problem of migration can be efficiently solved using principles of software architecture. We emphasize the need for architectural specification, through which such problems can be formally tackled.

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Thesis Abstract (M. Sc. (Engng))

Pattern representation and prototype selection for handwritten digit recognition by V. Vijaya Saradhi
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Department: Computer Science and Automation

1. Introduction

In this work, we present three ideas to increase the classification accuracy using the nearest neighbour classifier. These ideas are (i) combination of decisions using different representation schemes, (ii) redundancy removal using bootstrapped patterns, and (iii) selection of both features and prototypes at a time.

2. Combination of decisions of individual classifiers

In recent years, combination of classifiers has become an active area of research in the field of pattern recognition, particularly in HW digit recognition. There are several ways of combining the decisions of individual classification rules. These include voting, Dempster–Shafer formalism, and sum, product, mean, max, min rules. Here we propose a new modified voting for combining the decisions of individual classification rules. Four representation schemes are considered for experimentation apart from pixel-based representation. These are: i) Directional features, ii) Discrete cosine transform (DCT)-based features, iii) Wavelet transform-based features, and iv) Zernike moments. Final decision about the class label of the test pattern is taken as follows:

2.1. *When two representation schemes are involved*

When only two representation schemes are involved, the final decision based on majority voting may not work properly. The decision taken according to majority voting may be purely arbitrary in the case of combination of two representation schemes. Therefore, here we have considered the following combination rule.

Let $(\mathbf{X_i}, \theta_i)$ be the first nearest neighbour of the test pattern represented by one representation scheme. And let $(\mathbf{X_j}, \theta_j)$ be the first nearest neighbour of the presented test pattern using the other representation scheme.

$$\textit{final class label} = \begin{cases} \theta & \text{if } \theta_i = \theta_j = \theta \\ \textit{recompute the class labels} & \text{otherwise} \end{cases}$$

Recomputation involves the following procedure. Training patterns $\mathbf{X_i}$ and $\mathbf{X_j}$ are temporarily removed from the respective training sets. The key idea behind removing the training patterns is that by removing the *nearest* training patterns from both the representations, viz. $\mathbf{X_i}$, $\mathbf{X_j}$, the test pattern is assigned the class label of the *k*th neighbour if the class labels of *k*th neighbours match.

2.2. *When more than two representation schemes are involved*

When more than two representation schemes are involved, the test pattern is assigned a class label, according to majority voting.

$$\textit{final class label} = \begin{cases} \theta & \text{if majority voting} = \theta \\ \textit{recompute the class labels} & \text{otherwise} \end{cases}$$

Let the class labels given by the NNC using different representation schemes be $\theta_1, \theta_2 \ldots \theta_n$. If none of these class labels match, then recompute the labels. The recomputation of class labels is similar to the one which is used in the case of two representations.

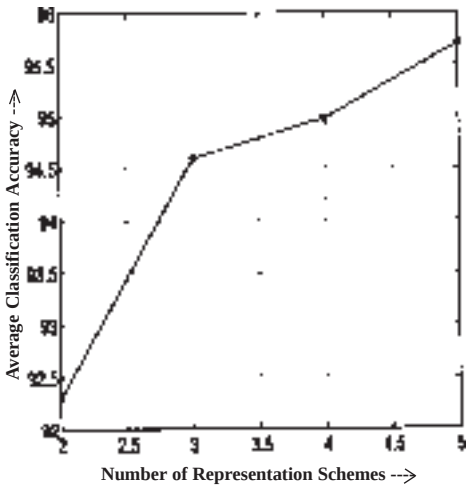

FIG.1. A plot between number of representations schemes involved in decision-making and average classification accuracy.

We have considered all the possible combinations and have found that the average classification accuracy is nondecreasing as the number of representation schemes involved in decision-making increases (Fig. 1).

3. Bootstrapping for efficient classification

In the second part of our work, we concentrate on selecting prototype from the bootstrapped patterns without compromising on classification accuracy. We propose two prototype selection schemes, viz. *threshold-based redundancy removal* and *mutual nearest neighbour removal* to remove the redundancy present in the data set. We introduce two terms *typical pattern* and *atypical pattern* to distinguish boundary patterns from nonboundary patterns. These two terms are defined as follows:

Let $\mathbf{X_i}$, $i = 1, 2 \ldots ., N$ be a pattern with class label ω_j, $j = 1, \ldots m$. Let $\mathbf{X_{i1}}, \mathbf{X_{i2}}, \ldots . \mathbf{X_{ik}}$ be the first k neighbours of $\mathbf{X_i}$.

Typical pattern: A pattern $\mathbf{X_i}$ is said to be a *typical pattern* if

$$C(\mathbf{X_{i\ell}}) = \omega_j \qquad \forall_{\ell} = 1, 2, \ldots, k \tag{1}$$

where C(**X**) denotes the class label of pattern **X**.

Atypical pattern: A pattern $\mathbf{X_i}$ is said to be an *atypical pattern* if it is not *typical pattern.* In other words,

$$C(\mathbf{X_{i\ell}}) \neq \omega_j \text{ for at least one } \ell, \ell = 1, 2, \ldots, k. \tag{2}$$

The performance of both the threshold-based redundancy removal and mutual nearest neighbour removal schemes were found to be working well both in retaining the classification accuracy and in selecting less number of prototypes (Fig. 2).

Table I
Comparative results

Data set	Validation set classification accuracy(%)	Test set classification accuracy(%)	No. of training patterns	No. of features	Remarks
Sonar	98.16	93.27	68	60	Prototype
Soyabean	95.11	83.46	60	35	selection
Sonar	51.43	93.27	104	31	Feature
Soyabean	89.29	94.40	307	25	selection
Sonar	98.07	93.27	62	24	Combination
Soyabean	97.39	89.86	141	17	

4. Feature selection and prototype selection using genetic algorithms

In the third part of our work, we have considered the problem of selecting both features and prototypes at a time using genetic algorithms. Using this kind of scheme, both computational time and storage requirements can be brought down by not significantly loosing the classification accuracy. The results on bench mark data sets are encouraging (Table I).

5. Conclusions

1. Combination of decisions of individual classifiers is observed to be better.
2. Redundancy removal methods proposed were found to be better than CNNC.
3. Number of typical patterns in the bootstrapped data is observed to be larger than the number of typical patterns in the original training data set.
4. Combination of feature selection and prototype selection using genetic algorithms is observed to be doing well.

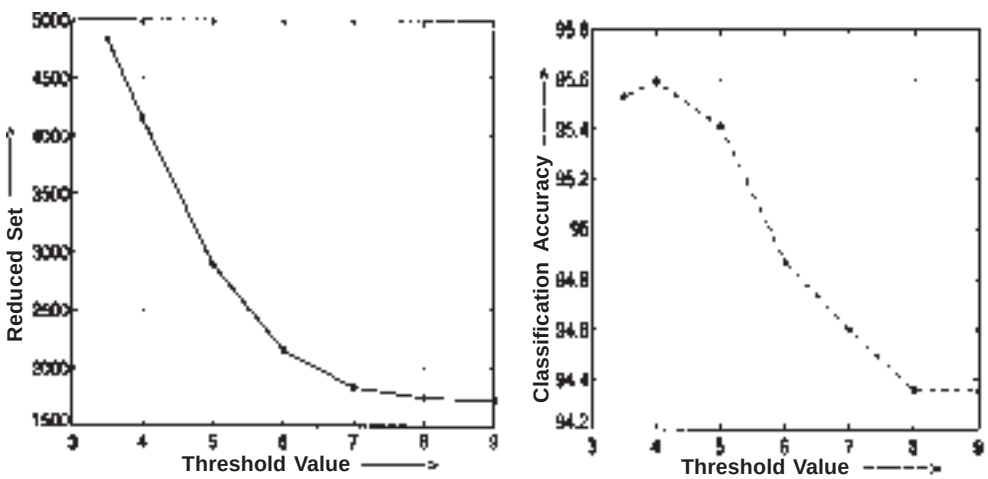

FIG. 2. A plot between threshold value and classification accuracy and plot between threshold value and typical patterns.

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