N93-26697

An Integrated Database With System Optimization and Design Features

S23-82
158370
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Abstract

A customized, mission-specific relational database package has been developed to allow researchers working on the Mars oxygen manufacturing plant to enter physical description, engineering, and connectivity data through a uniform, graphical interface and to store the data in formats compatible with other software also developed as part of this project. These latter components include an optimization program to maximize or minimize various criteria as the system evolves into its final design; programs to simulate the behavior of various parts of the plant in Martian conditions; an animation program which, in different modes, provides visual feedback to designers and researchers about the location of and temperature distribution among components as well as heat, mass, and data flow through the plant as it operates in different scenarios; and a control program to investigate the stability and response of the system under different disturbance conditions. All components of the system are interconnected so that changes entered through one component are reflected in the others.

Introduction

This specific project was initiated with the aim of providing data storage, classification, system design, optimization and simulation and control system design capabilities for the oxygen manufacturing plant that the Space Engineering Research Center at the University of Arizona has undertaken to build on Mars. Because of the multidisciplinary nature of the plant's design process, this integrated software project was designed to provide uniform access to all the different groups working on the design and testing of the plant. This project consists of the following principal components (see *Figure 1*):

i) A relational database of component and model libraries with system integration capabilities;

ii) An optimization system to maximize specified performance criteria while meeting weight, thermal, cost and other constraints.

iii) A visualization system for animation of the plant's dynamics;

iv) A control design system associated with data collection equipment connected to an experimental setup.

This report focuses on the technical features and current status of the first two of these principal components.

Current Project Status

Relational Database

The design and implementation of the database entry, organization and storage program has been completed. A brief description of the program and its objectives and design philosophy were provided in earlier progress reports[1,2]. In essence, components of the plant are abstracted into simple functional databases which are then connected in a compatible manner to produce necessary connectivity data to other programs. The program, implemented in the FoxPro 1.02 environment on a 80386-based personal computer, features libraries of component types (e.g. pump, heat exchanger, compressor, etc) as well as libraries of specific manufactured models of each component type. The first set of libraries sets up fields for the general characteristics of a component type (e.g. the flow capacity of a pump or heat exchanger), in effect creating blank templates for actual data entry. The second set of libraries contains the actual data supplied by the manufacturers of specific models of components or data generated in house for equipment

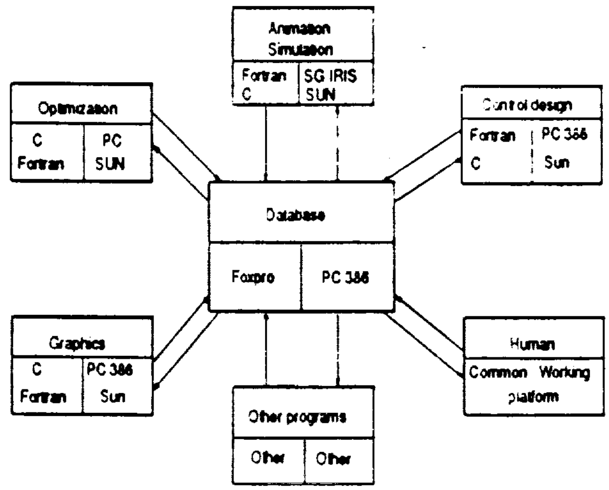

Figure 1. Overview of integrated database system

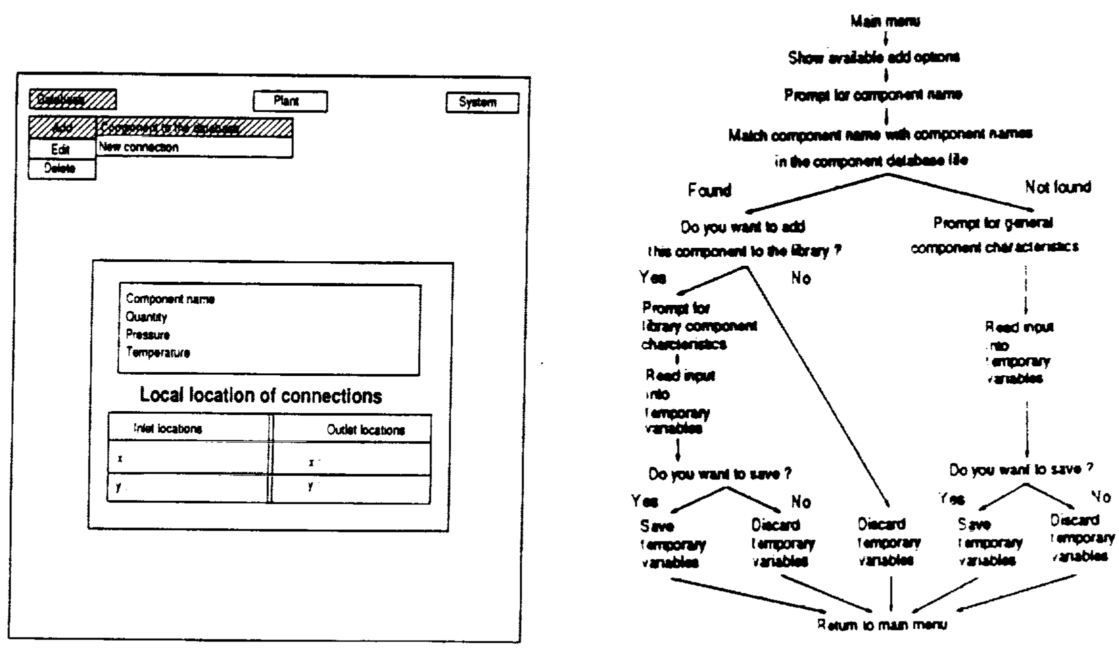

Figure 2. Entry of general component characteristics and associated flowchart

designed in university laboratories. Similarly, libraries of connection types and specific models of connections are maintained for pipes, cables and couplings. Each of these libraries can be accessed from a graphical user interface using a pointing device. In addition, the user can enter new component types of his own, edit the existing database or delete components from the database using simple point-and-click commands. A sample new component addition menu set and its associated flow chart are illustrated in *Figure 2*.

Once libraries of components and connections are built, the user can pick any number of different models of components and connections, and install them in a model of the plant of arbitrary design. This is also accomplished by simple point-and-click commands with the program guiding the user through the different steps. A graphical display system to enable the user to view the current status of the layout of the plant is also incorporated in the program and can be called from a drop-down menu using a pointing device. *Figure 3* illustrates some of the menu items that are available at this stage. When the user is finished installing components and connections in the plant, the program links the installed components by the proper connections and checks for any physical interference between any two components or between a component and the frame of the plant. In the event a physical interference is found, the program attempts to relocate the components so that the interference is eliminated. If no positions can be found to eliminate the interference the user is prompted to enter a new component model.

A complete report about the design and use of the database program has been written and is available at the Computer-Aided Engineering Laboratory[3,4].

Optimization Software

A new customized software system has been developed to optimize the packaging of the oxygen manufacturing plant. The principal purpose of this system is to ensure that the components of the plant are located relative to each other in such a way that user-defined cost functions are minimized. The system, which can be called from a drop-down menu using a pointing device, reads all the information it needs about the properties and connections of the components in the plant from the relational database and then relocates the components iteratively until the cost or objective function that has been defined is minimized. At the present time, two different objective functions are used. The first objective function, O_1, consists of a weighted sum of all heat and pressure losses that occur within the plant through radiation between components and from connecting pipes, convection through fluid flow, conduction along pipes and fluid friction within pipes. Because of the different types of losses included in the function, system parameters (e.g. temperatures at desired points or surfaces or pressures at certain inlet or outlet positions) occur in nonlinear form in the function. The second objective function, O_2, is made up of a weighted sum of component and connection weights and costs. The optimization program searches the space of possible locations for components in the plant plus all possible component and connection models that can be substituted for each component and connection model to reduce the value of both objective functions to a minimum.

The optimization process is complicated by the fact that some of the variables that change the values of the two objective functions are continuous while others are discreet. For example, the locations of the components in the plant, specified by their coordinates in a reference frame, are continuous variables whereas their sizes, costs and weights and discreet because they change abruptly from one model to another. As a result, the optimizing program proceeds in four different stages. In Stage 1, the program divides up the frame of the plant into n equal regions where n is the number of components in the plant. It then places the initial (user-specified) set components in each of the regions making sure that there is no physical interference anywhere in the plant. In doing that each component is represented by the smallest rectangle that complete encloses the component (see *Figure 4*). In Stage 2, the program relocates each component in all possible regions computing the value of O_1 in each case. The configuration that results in minimum O_1 is retained. In Stage 3, the program substitutes each component in each region and each connection among them with all possible models from their respective libraries. In this stage the minima of both O_1 and O_2 are sought. In Stage 4, the set of components and connections resulting in minimum O_1 and O_2 are subjected to fine-tuning adjustments within their own regions to reduce O_1 further. Stage 1 is accomplished using a novel approach that employs modulo arithmetic. Stage 2 uses a modified brute-search method, Stage 3 uses a brute-force search method, and Stage 4 uses the steepest-descent method. *Figure 5* shows the different stages of optimization by a flow chart.

The program's output can be viewed interactively as it searches for the optimal configuration or graphically whereby the program displays the initial (nonoptimal) and final (optimal) configuration of the plant, together with figures for total heat and pressure losses. *Figure 6* shows different configurations tried by the program for a nine-component design. The system is currently being enhanced to export data about the optimal configuration it finds to the relational database program so that it can update its appropriate databases and export them to other programs that make up the integrated system.

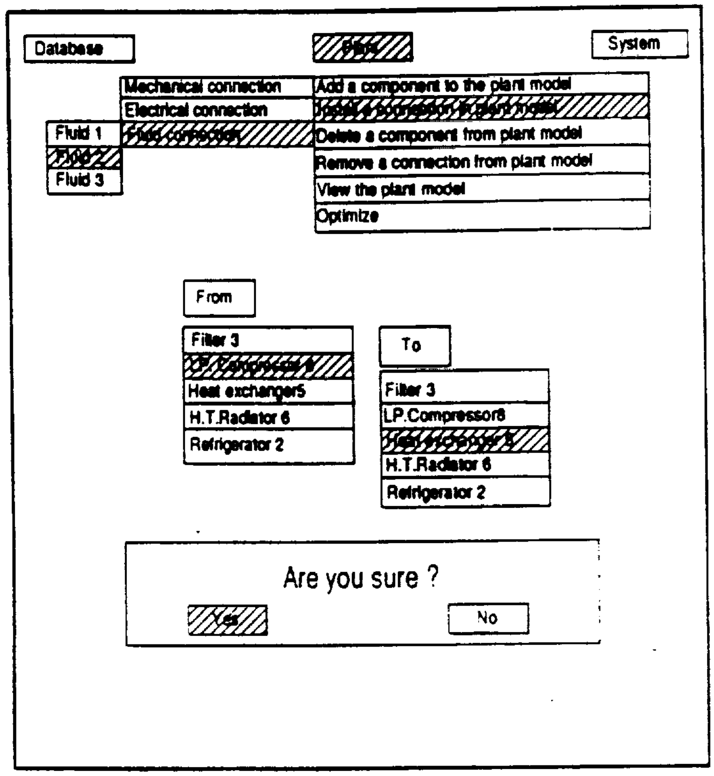

Figure 3. Installing components and connections in plant model

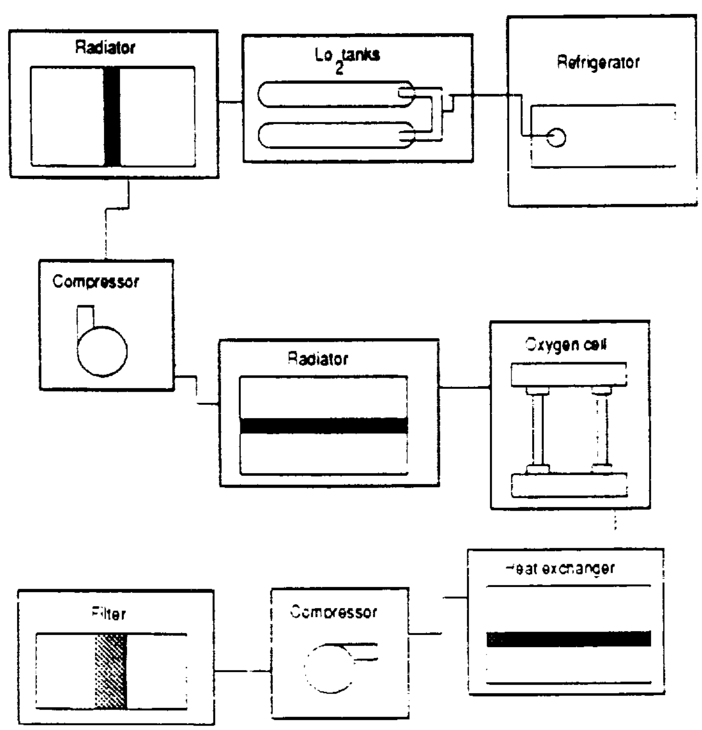

Figure 4. Components enclosed in rectangles

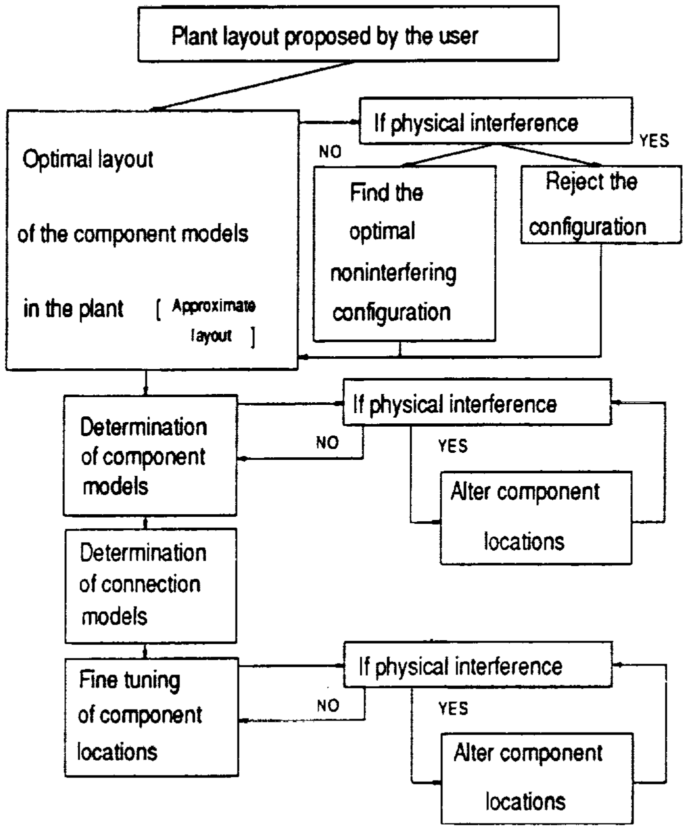

Figure 5. Stages in optimization process

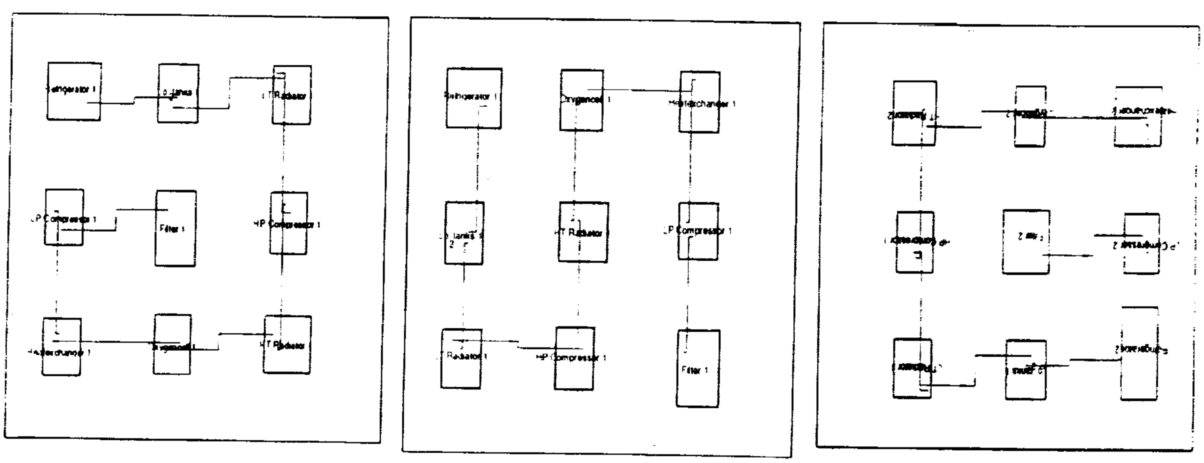

Figure 6. Successive configurations in optimization process

A complete report about the design, operation and current status of the optimization program has been written and is available at the Computer-Aided Engineering Laboratory[4].

References

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