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An Approach to Automated Synthesis of Solution Principles for Transducer Designs

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Summary

In a last year's proposal [1], a framework for supporting conceptual design, and a research method to achieve it, were proposed. The framework should support alternative formulations of required device functionality, automatically offer a range of alternative solution principles to achieve that functionality, and support embodiment and envisionment of these principles. It was proposed [1, 2] that the automated generation of solution principles could be achieved by further developing the data structure and search algorithm of an earlier program Functional Synthesiser, developed at the EDC, for synthesising solution concepts for mechanical designs [3]. We have developed the data structure and Search algorithm for the functional synthesiser to the point where it can achieve the basic operations set out in the proposals [1, 2]. The research method adopted is that proposed in [1]: essentially we have used the design problems associated with the microaccelerometer as a case history to suggest a suitable knowledge base for the system.

The problem of associating physical principles (e.g. Bernouilli's law) with enough context to enable the computer to 'invent' devices which harness these effects is considerable, and we have not attempted to do it at this stage. Instead, we have a database of simple embodiments of these principles, coupled with an algorithm for combining them to achieve an overall function.

The data structure and algorithm are implemented, and the database presently contains about forty physical devices and effects; the program generates solution principles to a design problem, described in terms of the input (signal to be measured) and the required output (medium), by combining these physical devices and effects exhaustively.

1 Introduction

Fig.1 presents a framework for supporting conceptual design, as proposed in the last year's RACE/EDC workshop [1]. The framework should support alternative formulations of required device functionality, automatically offer a range of alternative solution principles to achieve that functionality, and support embodiment and envisionment of these principles.

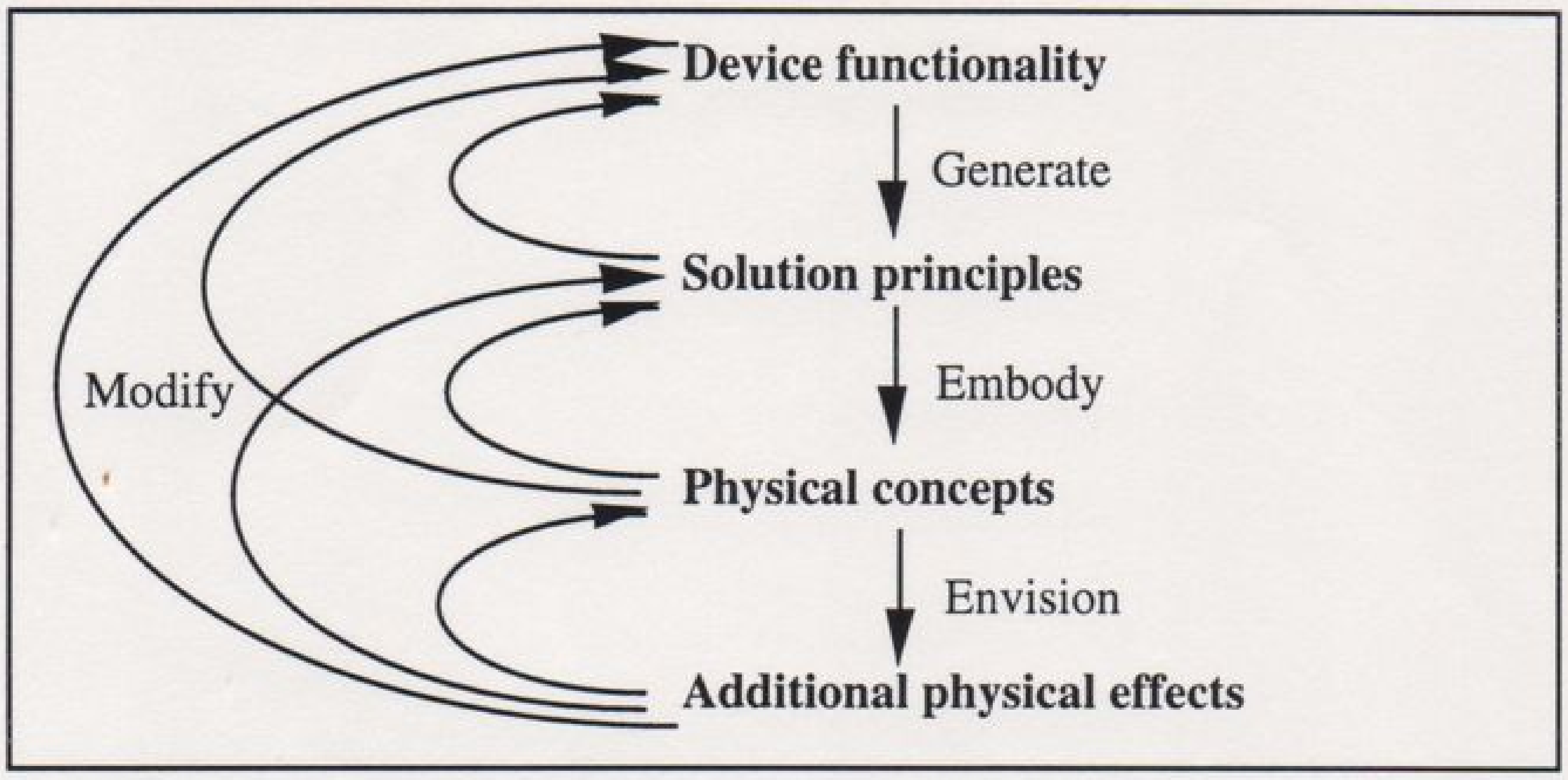

Fig. 1 Proposed Conceptual Design Framework

So far, we have concentrated on the first two of the above objectives: (i) how alternative formulations of required device functionality for the case of sensor designs can be supported, and what database, data structure and search algorithm is needed to automatically offer a range of alternative solution principles to achieve that functionality. The essential idea, as illustrated in [1, 2], is that a wide range of designs are, or can be looked at as, combinations of common elementary devices and effects. Therefore, if these elementary devices can be systematically identified and suitably represented so that they can be combined automatically to suit a specified functionality, this will offer a range of alternative solution principles. This entails three major tasks: (i) identify elementary devices to develop a database of devices, (ii) develop suitable data structures and algorithms, and implement them into a system, and (iii) test and evaluate the system.

In order to develop the knowledge needed for developing the database of elementary devices and effects, we have analysed a range of existing designs, including the accelerometer designs, with the aim of identifying their common elementary devices.

The data structures and algorithms have been developed by further developing the concepts of data structure and algorithm of Functional Synthesiser [3]; Functional Synthesiser was originally developed at the EDC for generating conceptual design solutions to mechanical motion transmission problems, expressed in terms of given inputs and required outputs, as combinations of simpler motion transmission elements.

Testing was done by comparing the solution principles, generated by the program, with those considered in the accelerometer design case history.

2 Present Definition of the Solution Principle Synthesiser

2.1 Terms & Concepts

There are three sources of knowledge about elementary devices: **definitions** which can be used to measure any of the parameters in the definition by measuring its other parameters and then operating them with one another as per definition (for instance that mass is the product of volume and density: if a larger mass would help to amplify a certain effect, this could be achieved by increasing the volume of the object which is acting as a mass, or the density of the material from which it is made); **physical principles** which can be a used in a number of ways in a device (such as using Newton's laws of motion for measuring mass, measuring force, or measuring acceleration); elementary **devices / effects**, each of which makes use of one or physical principles (c.f. Prof. Taura's natural laws).

The system is conceived as fitting together a number of elementary **devices**. Each device takes as its input a **signal** in a given **medium**, e.g. an acceleration or a voltage, and produces an output signal whose **message** is some function of the input signal (e.g. proportional, or the derivative with respect to time), and whose medium may be the same as or different to that of the input signal.

In addition, the system will require an amount of intrinsic **basic knowledge**, such as an understanding of the process of calculus, and facts such as acceleration is the time derivative of velocity.

2.2 Data structures

2.2.1 Devices/Effects

The current template for each device is shown in Fig. 2. The sketch is intended for display to the user at the end of the synthesis process, to show schematically what solution has been found. The pointers to the physical principles are currently not for the computer's use: In future, it may be possible for the computer to develop its own devices, and these slots will record the physical principles which were used.

DEVICE/EFFECT TEMPLATE	
NAME	
SKETCH	
CAUSAL DIAGRAM	
PRINCIPLES 1 2 3	
INPUT	OUTPUT
	f (i)
ABS/REL	MEDIUM ABS/REL
INCIDENTAL INPUTS	
INCIDENTAL OUTPUTS	
SENSITIVITIES	

Fig. 2 Device/Effect Template

2.2.2 Physical Principles

The template for physical principles is shown in Fig. 3. At present these are not used directly by the system, but we thought it important to have a formal record of each principle invoked, together with a reference where more details about the principle can be found.

PHYSICAL PRINCIPLE TEMPLATE
NAME
EQUATION
DEFINITION OF TERMS
REFERENCE

Fig. 3 Physical Principle Template

When any device is incorporated in a solution, the system thus at least knows which physical principles have been used by that device and could refer the user to an appropriate reference for further information.

2.3 Algorithm and Its Implementation

The Algorithm for the operation 'Measure' is shown in Fig. 4. At present, this is a simple frontal search which should (eventually) find any solution to the problem which exists, given the known devices and the limit on the number of devices which can be strung together.

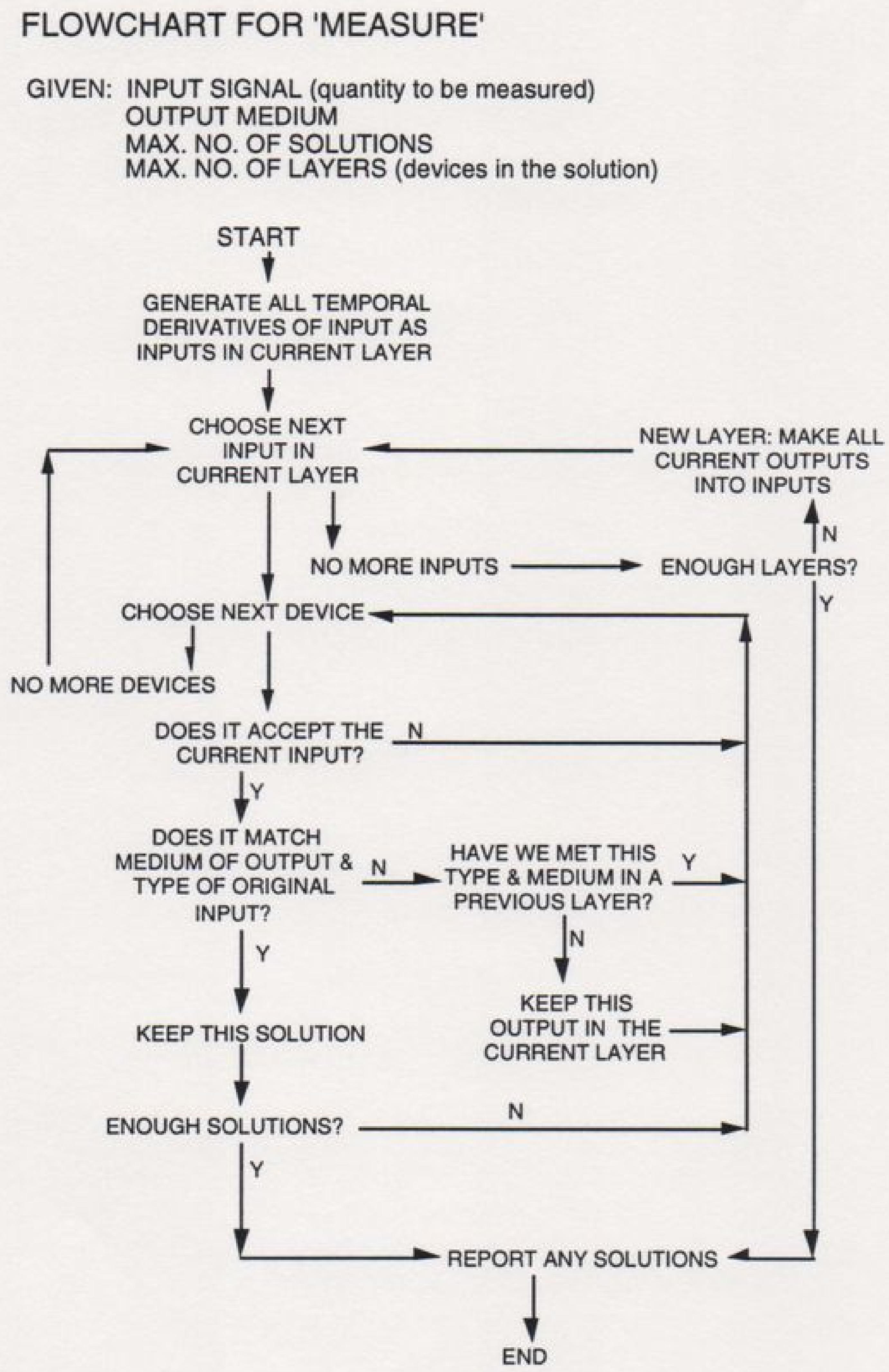

Fig. 4 Flowchart for 'Measure'

The process of attaching a new device to a current output stream firstly involves finding the next device in the list which accepts the relevant medium as its input. The device then 'returns' the new medium type, and an expression of the process which is applied to the signal. The system is implemented on a LispWorks (a registered trademark of Harlequin Limited, UK) package, using Common-LISP language.

In future, the program should be able to return the process which is applied to the signal in a reverse polish form, so that successive processes can be built up easily; symbolic simplification of the overall process will be required at each stage, so that the system will know when it has generated an output signal which is proportional to the initial input, rather than being some complex function of the input and/or its derivatives.

3 Evaluating the System: Accelerometer Design Case Study

We wanted to test and evaluate the system by setting it the task of generating solution principles to the accelerometer design function, as was set by the designers in the case study [4], and compare these solutions with those that the designers considered. We wanted to check if the system suggested solutions that the designers considered, and, more importantly, whether it suggested solutions which the designers did not consider (which would illustrate the potential of the system to expand designers' thinking by widening the range of alternatives to consider).

We allowed the system to use a database of eighteen elementary devices, and set it the task of generating all possible solution principles to an accelerometer design problem, expressed as a transformation between an acceleration as the input signal and voltage as the output medium. We restricted the allowable number of devices and effects, to be used in a single solution, to six.

-acceleration-> **interia** -force->

Fig. 5a. An example of an elemetary device: interia to measure an acceleration as a force

-acc.-> **inertia** -force-> **force-stress** -stress-> **thermoelastic** -voltage->

-acc.-> **inertia** -force-> **force-stress** -stress-> **piezoelectric** -voltage->

-acc.-> **inertia** -force-> **spring** -position-> **strain-gauge** -resistance-> **resist-volt** -voltage.->

-acc.-> **inertia** -force-> **spring** -position-> **strain-gauge** -resistance-> **resist-volt** -voltage.->

-acc.-> **inertia** -force-> **spring** -position-> **tunnelling** -current-> **current-volt.** -voltage.->

-acc.-> **inertia** -force-> **spring** -position-> **capa.-distance** -capa.-> **capa.-volt** -voltage.->

-acc.-> **inertia** -force-> **spring** -posi.-> **posi.-area** -area-> **area-capa.** -capa.->**capa.-volt** -voltage.->

-acc.-> **inertia** -force-> **spring** -posi-> **tunnelling** -curr.-> **widiemann** -rotation->**widerthim** -volt.->

-acc.->**iner.**-force->**spring**-posi-> **tunnel.**-curr.-> **peltier**-temp.-> **resi-temp**-resi.-> **resi-volt**-resi.->

Fig. 5b The Solution Principles Generated by the Program

The total number of solutions was nine (see Fig. 5b), which included the solution (number 5 from the top in Fig. 5b) the was considered by the designers of the case study, and others, including the condenser type solutions (numbers 6 & 7 from the top) which are the major competing principle to this design. More importantly, the system suggested several other, new principles such as the one that uses thermoelastic effect (number 1 from the top) to transform stress into voltage, that were not considered either in this case study or in the other ones cited in literature, which highlighted the potential for the system to offer new, wide ranging alternative solution principles for the conceptual stage.

4 Future Work

The overall scheme of work can be viewed as shown in Fig. 6. At present, the basic algorithm for stringing devices together has been developed and implemented, a number of improvements, as proposed below, can be made.

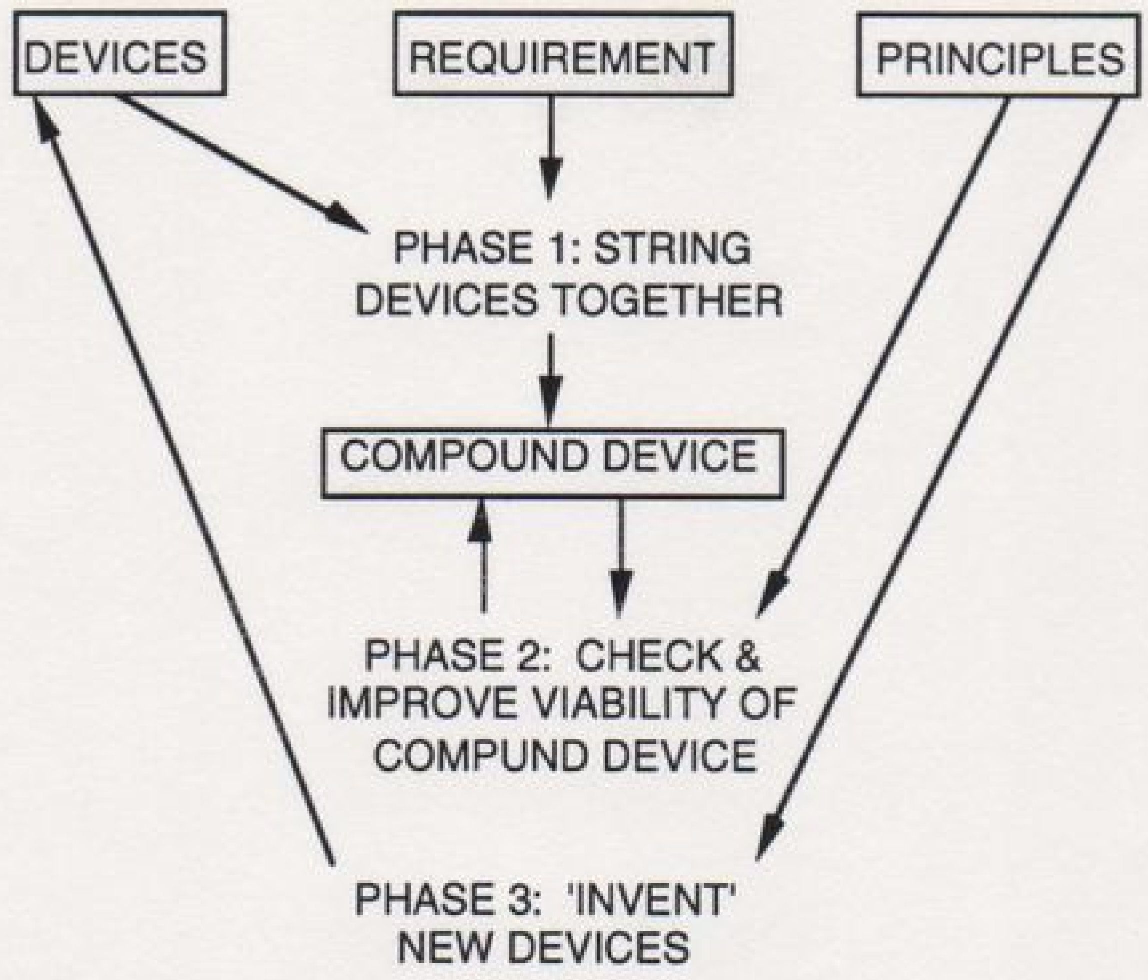

Fig. 6 Overall Scheme

Phase 2 is concerned with vetting the viability of proposed designs, in particular by seeing whether parts of the design might be adversely affected by side effects emanating from other parts of the design, or from the environment. Although the template for each device contains slots for side effects and sensitivities, it is thought that the system will need a means of reasoning about the physical principles themselves in order to carry out a proper evaluation.

If phase 2 is successful, it opens the possibility for phase 3, in which the physical principles might be used to 'invent' new devices directly.

Apart from continuing to develop the database of physical devices and effects with new devices and effects, next set of problems to be solved are:

Phase 1:

1 Formalising the difference between absolute and relative values. At present, the program simply looks at the input flags for each device (see template) and matches them to the current output. The strategy of using two absolute measurements to determine a relative measurement (and all its variants) should also not be too hard to implement.

2 Understanding how to use discrete events as a means of measuring a continuous phenomenon (e.g. pulses from the two ends of a rotating shaft as a means of measuring the twist in the shaft).

3 Adding heuristics to the search algorithm so that the paths which are likely to lead to a solution are explored before those which seem less likely to do so.

Phase 2:

1 Handling side-effects, and detecting unintentional feedback loops

2 Sensitivity to scale effects, and adjustment of the amplification in the system (including feedback) to produce a response of appropriate magnitude.

5 References

[1] Chakrabarti, A. "Towards a Support Framework for the Generation and Exploration of Conceptual Design Solutions" in Workshop on Knowledge Sharing Environment for Creative Design of Higher Quality and Knowledge Intensiveness, 12-13 January, 1995

[2] Kiriyama, T. and Johnson, A.L. "Functional Modelling for the Design of Micromechanisms" in Workshop on Knowledge Sharing Environment for Creative Design of Higher Quality and Knowledge Intensiveness, 12-13 January, 1995

[3] Chakrabarti, A. “Designing by functions”, PhD thesis, Cambridge University Engineering Department, 1991

[4] Burgess, S., Moore, D., Edwards, K., Shibaike, N., Klaubert, H. and Chiang, H-S. "Design Application: The Design of a Novel Micro-Accelerometer" in Workshop on Knowledge Sharing Environment for Creative Design of Higher Quality and Knowledge Intensiveness, 12-13 January, 1995