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DETECTING SIDE EFFECTS IN SOLUTION PRINCIPLES

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Conceptual Design, Side effects Generation, Concept Evaluation, Solution Principle

1 Introduction

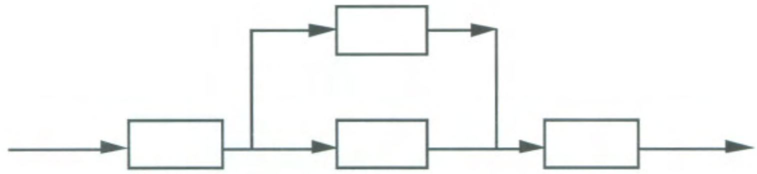
A principal task at the conceptual stage is to consider the widest possible selection of solution principles, for subsequent embodiment into viable concept variants. This becomes particularly difficult when the scale of the design is radically different from a designer's normal experience, e.g., in the mechanical design of small artefacts. In a previous paper [1], we described a framework for (i) supporting alternative formulations of device functionality, (ii) generation of alternative solution principles to fulfil these, and (iii) embodiment and envisionment of these principles. Our progress in developing a representation for device functionality, and an automatic search algorithm for synthesising solution principles for transducer designs was also reported.

This paper discusses the issue of identifying side-effects in conceptual solutions. Presently, side-effects are either suspected from experience or detected from field tests, which are prone respectively to misjudgement and cost commitments. As several avoidable accidents due to unforeseen side-effects indicate [2, 3], detection of these needs more systematic support during design itself. The paper categorieses the types of side effects that need identifying, and proposes a method for supporting their identification, a task never supported on computers before.

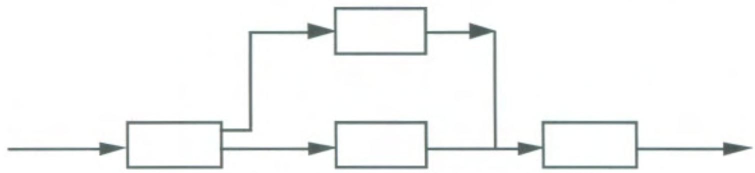
2 Side Effects in Solution Principles and Physical Concepts

Side effects are defined here as effects whose outputs affect the intended operations of a system. Many systems (such as sensors) function as chains of physical effects, and any additional, unintended physical effect which becomes active and changes the intended I/O of these systems is detrimental to their operation.

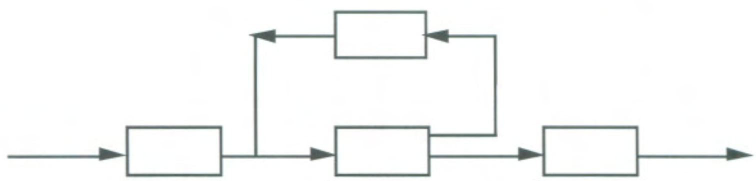
Central to this process is the activation of additional physical effects. Activation of a physical effect requires two things: the right input and the right context parameters. For instance, activation of a piezoelectric effect requires stressing (input) of certain crystals (context). Identification of side-effects is therefore a process of detecting which inputs and contexts are available in the circumstances in which a given system would work, and from these, identifying which physical effects might get activated as a result. Activation of these potential effects generates further outputs, and therefore makes it possible for further physical effects to be activated. The outputs, from some of these effects, would be of the same kind as the intended I/O of the system under investigation; these are potential side effects for this system, and need further investigation to check for the significance of their effects on the system.



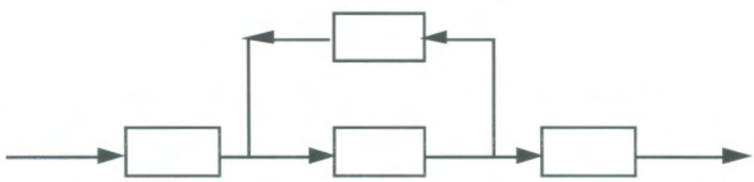
a. Feed-forward effect (chain) using intended system input



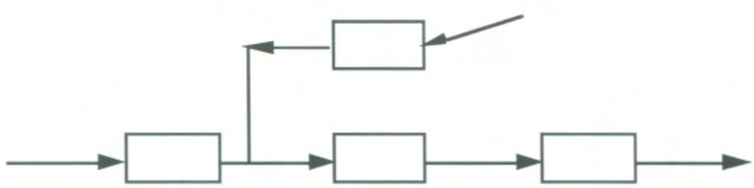
b. Feed-forward effect (chain) using unintended system input



c. Feed-back effect (chain) using intended system input



d. Feed-back effect (chain) using unintended system input



d. Effect (chain) using external input

Figure 1 Various Possible Side Effect Chains

The input and context parameters can arise in several ways. The most obvious ones are the intended inputs, outputs and context parameters to be used in the chain of effects that constitute a solution principle of the system being designed, and those unintended but consequential of the use of these effects. As a solution principle can be embodied into a physical concept in several ways (e.g., Hooke's law can be embodied as a beam, a tension bar or a torsion bar), each embodiment brings with itself several additional context parameters, thereby extending the range of physical effects that can be activated as a result. The environment(s) within which the system has to work can also introduce additional input and context parameters. Misuse and abuse (which means use in unintended or contra-intended contexts or inputs) can also introduce additional activation parameters. All of these must be considered when trying to identify potential side-effects.

Side effects can operate in a number of ways (see Figure 1). They usually operate as *feed-forward* or *feed-back* chains. A *feed-forward* chain takes some inputs from the initial part of the solution principle or its embodiment to drive a set of additional physical effects to generate an output of the same kind as that in a latter part of the solution principle or its embodiment. A *feed-back* chain takes its input from a latter part of the principle or its embodiment and produces output(s) of the same kind as that in an initial part of the chain. Each of these can happen using intended inputs of the solution only, unintended inputs only, or combination of these as well as external inputs from the environment. It is also possible for effect chains to be activated by external inputs alone. It may be possible for an effect chain to start and end at the same effect. For instance, a resistance may generate a current in response to a voltage, but this also generates heat which changes the temperature of the resistor, changing in turn its resistivity and thereby the current it generates.

A support for identifying side-effects, therefore, should support (i) detection of additional effects that can be active for a given solution principle and its given potential embodiments for it to work in given ways in given potential environments, (ii) identification, among these effects, of those which affect the intended inputs and outputs of the solution considered, (iii) chaining of these effects together to see which of these effect-chains could be directly or indirectly responsible for causing side-effects for the solution, and (iv) see if these effects are significant in size for them to threaten the functioning of the solution. The following section presents a more detailed account of this general approach.

3 A General Approach for Identification of Potential Side Effects

There are five steps involved. These are: identification of inputs, identification of context parameters, detection of activated physical effects, identification of physical effect chains affecting I/O of solutions, and evaluation of the significance of these effect chains.

3.1 Identification of inputs

These can be (i) intended inputs and outputs of the system under consideration (such as a resistance generating a current through it as a result of a voltage applied across it), (ii) indirect inputs and outputs of the system (such as a resistance generating heat as a result of current flowing through it), (iii) inputs arising out of (potential) misuse or abuse (such as the use of the tail of a teaspoon as a screwdriver, or not putting a public phone back into the hook after use, leading to unintended tensile forces at work on the telephone cord), (iv) inputs arising out of the environment of use, misuse or abuse (such as unintended accelerations experienced by a pressure sensor used in a car, or perhaps getting in contact with dirt in an excavator application).

3.2 Identification of context parameters

These can be confined to (i) context parameters and their consequential parameters for a single intended effect, (ii) context and consequential parameters for multiple intended effects (for instance, two parts of a system are physically connected in a thermally conductive way, so that heating of one leads to heating of the other), (iii) from the physical embodiment of an effect, (iv) from the interaction of the embodiments of the effects, (v) from the interaction of the structure and the environment of use, misuse or abuse. Identification of context parameters is strongly coupled to modelling a system in a particular way (such as viewing a sign-post under wind-loading as a beam), and to a large extent this is driven by the prediction of a physical effect that is likely to come into play. This vicious cycle is particularly hard to break, and the modelling effort required to predict all possible effects can be considerable.

3.3 Detection of activated physical effects

This critically depends of the range of the database of physical effects (or devices) that are considered. There are two issues. One is that the same effect can be used to generate different outputs depending on the input and context. The second is that the same effect can appear in composite forms (for instance, a spring can be described as a single effect or as a composition of three effects, namely force-to-stress, stress-to-strain, and strain-to-position changes). The number of physical effects may be a problem.

3.4 Identification of physical effect chains affecting I/O of solutions

Once all the activated physical effects are detected, the synthesis algorithm can be used to chain them together, such that only those which end up with an output of the same kind as those involved directly in the system's chain of effects are flagged.

3.5 Evaluation of the significance of these effect chains

This is to find out whether or not a side-effect chain could significantly affect the I/O of a system effect-chain. It amounts to comparing the estimated size of the output of the side-effect chain with the size of the output of the same kind in the system effect chain. This requires, in many cases, an estimation of likely loadings and parameter values in un-tested situations, and may be hard to obtain, making estimations difficult.

The next section focuses on how this approach could be used to identify side-effects at the solution principle level, ie, when no commitments have been made as to how the effects in the solution principle are to be embodied.

5 Identifying Side Effects in Solution Principles

At the solution principle level, the possible inputs are: intended inputs of the effects in the system chain and their consequential inputs, and external inputs. Each effect needs some context parameters in order to work (such as a metal surface being required for photo-emission), which therefore requires that it exists (e.g., a solid metal surface must be available). This means that this context has additional parameters which are also available for exploitation (such as conductivity of metals, strength and ductility of solids etc), which may allow additional side-effects to be invoked (such as expansion of the metal if a high temperature was available as an input). The process of identifying side-effects can start with a list of probable external inputs from the designer (or, alternatively, all effects whose context parameters exist could be activated). These, and the I/O of the considered system chain, could be used to select probable physical effects from the database. This will generate additional inputs for consideration, which in turn could be used to generate another layer of physical effects, and so on, until no further physical effect can be generated, or that the new effects generate outputs of the same kind as those in the original solution principle. These effects can then be joined together, taking into consideration their causality (effects generated in a certain layer must precede those produced after these and before those preceding their generation).

The procedure could take two alternative forms: (i) a *generate-test* loop, or (ii) a *generate-only* loop. The *generate-test* loop should first find all the inputs that are available from the effects in the solution principle (as well as those that may have been suggested by the designer as being probable external inputs), and using these to generate a list of effects which would take these as inputs. The approach should then check if the context parameters required by these effects could be supplied by the direct and consequential context parameters of the effects of the solution principle, and prune the list of effects based on this criterion. The new list of effects could then be used to generate their possible outputs as inputs to be added as available for search for further side effects.

In the *generate-only* loop, effects in principles, as well as those suggested by the designer as probable external inputs, could be used to enlist possible inputs for side-effects to occur. These effects could also be used to enlist context parameters and their consequential further context parameters which could be used to activate side-effects. These inputs and contexts could then be used to search for side-effects, whose outputs could be fed as further inputs for search for further side-effects. The process should end when no further side-effect could be identified. The generate-only approach seems more efficient if an easy means for identifying context parameters could be devised, but generate-test approach seems simpler to implement.

Two significant tasks remain. One is to find a suitable way for modelling effect chains, especially when different properties of the same structure (such as heat transfer properties of the resistor rather than its electrical properties) are involved in different physical effects. The other is to find a suitable way of modelling context of a physical effect, so that additional context parameters can be identified or checked.

6 Some Examples from an Accelerometer Design Case

Micro-accelerometers are accelerometers of small size (upto 2mm) which find wide application, especially in the car industry. The following are some of the possible side-effects on an accelerometer, and illustrate the various modes by which side-effects can show up.

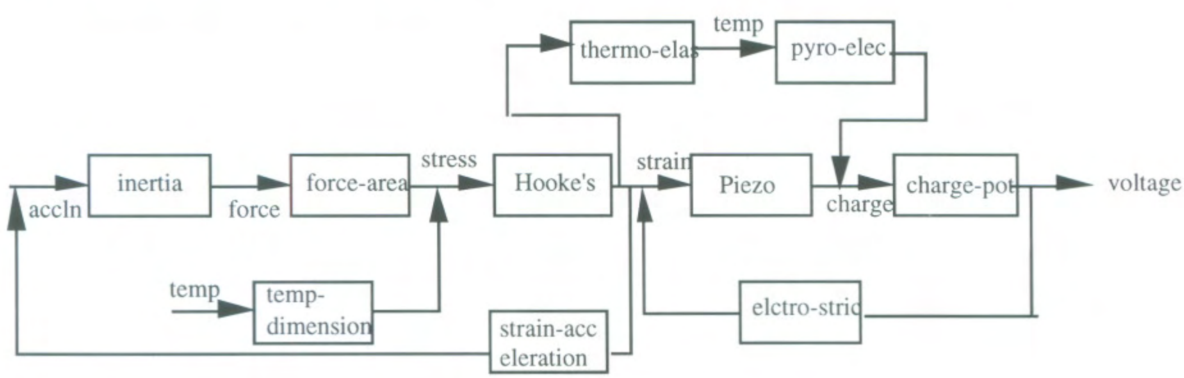


Figure 2 Some Examples of Side Effects of an Accelerometer Principle

Fig. 2 Shows a solution principle for an accelerometer, where acceleration is sensed using a *mass-spring* combination to generate a strain and using a *piezo-effect* (shown by the straight chain of blocks running horizontally across the figure). The top chain connecting a *thermo-elasticity* block to generate a temperature from the strain, and *pyro-electricity* to generate a charge together forms a *feed-forward* chain (as in Figure 1a), which can distort the strain to be measured. Similarly, the bottom block showing a connection between voltage and strain via an *electro-striction* block represents a *feed-back* effect (as in Figure 1c) that can distort the strain to be measured as a result of an un-intended *electro-striction* effect. Finally, if temperature change is an *external* input (from the environment), this could set up distortion of the object undergoing strain, thereby changing the stress to be measured (an example of Fig. 1e). The connection between strain and acceleration, shown via the *strain-acceleration* block at the bottom of the diagram, shows a *feed-back* acceleration of varying magnitude created due to vibration in the proof mass. These are but a few examples of how various side-effect chains could affect the functioning of a solution principle.

7 Conclusions and Further Work

This paper formulates the side-effects detection problem as a problem of generating effect-chains which produce an output of the same kind as an I/O within the solution principle. Side-effects can occur due to inputs and contexts supplied by parameters of a solution principle, its embodiments and the environments of its intended, un-intended, and ill-intended uses. A *general* approach for identifying and testing the significance of possible side-effects is proposed, and two, alternative, *specific* approaches for doing this at the solution principle level are suggested. The main challenges lie in modelling a solution-principle and its context in a way that makes it amenable to efficient search for its probable side-effects. The program has now been written, and is under further development and testing. Tests underway include case studies [4, 5] of micro-accelerometer designs.

References

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