**RESEARCH NOTE**

Modeling and Simulation of Digital Systems Using Bond Graphs

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**ABSTRACT**

Bond graphs are suitable tools for modeling many types of dynamical systems and can model these systems consisting of mechanical, electrical, fluidic, and pneumatic sub-systems. The advantage of a bond graph is that it can model non-linear systems and combinational systems. In this paper, the authors utilize bond graphs for modeling mechatronics systems. Mechatronics systems consist of mechanics, electronics, and intelligent software. Many of these systems have digital sections that are constructed by logical circuits (hardware by transistors and now mostly by chips). The authors present a methodology to implement these mechatronics systems by bond graphs.

**Keywords:** Bond Graph, Digital and Logic Circuits, Dynamical Systems, Mechatronics, Modeling

**INTRODUCTION**

Bond graph was introduced by the late Henry M. Paynter (1923-2002), professor at MIT & UT Austin, with the introduction of junctions in April 1959. In a period of about a decade, most of the underlying concepts were formed and were put together into a conceptual framework and corresponding notation (Paynter, 1961, 1992). In the sixties the notation, e.g. the half arrow to represent positive orientation and insightful node labeling, was further elaborated by researchers, in particular Dean C. Karnopp at UC Davis (Ca); and Roland C. Rosenberg (1968, 1974, 1990), at Michigan State University (Michigan) who also designed the first computer tool (ENPORT) that supported simulation of bond graph models [Rosenberg, 1965, 1974]. In the early seventies Jan J. Van Dixhoorn (1972; Evans et al., 1974) at the University of Twente, NL, and Jean U. Thoma (1975) at the University of Waterloo (Ontario) were the first to introduce bond graphs in Canada and Europe, respectively.

These pioneers in the field and their students have been developing these ideas worldwide (Karnopp et al., 1979). Jan Van Dixhoorn realized that an early prototype of the block-diagram-based software TUTSIM could be used to input simple causal bond graphs, and about a decade later, resulted in an
PC-based tool (Beukeboom et al., 1985). This laid the foundation for the development of truly port-based computer tool 20-sim at the University of Twente (Broenink & Breedveld, 1988) (www.20sim.com). He also initiated research in modeling more complex physical systems, in particular thermofluid systems (Breedveld, 1979). In the last two decades, bond graphs either have been a research topic or are used in research projects at many universities worldwide and have become part of engineering curricula at a steadily growing number of universities. In the last decade, their industrial use has become more and more important.

Logic circuits are also very important tools for implementing logic by electronic circuits. Initially, these circuits were used for implementing necessary logic in computers. In fact the existence of computers owes a lot to these circuits. After production of electronic chips the size of these circuits decreased considerably and thus increased their popularity. However, implementing logic by transistors is still used. Nowadays these circuits exist in most of the electronic systems, and transistors and chips can be readily found on such electronic circuits and boards.

Mechatronics systems utilize mechanics, electronics and software. These systems have very large usage, and their usage is increased daily. In electronic sub-systems of these systems logical circuits are used very largely. Because bond graph is a powerful tool for modeling electrical and mechanical systems, it is also very suitable for modeling mechatronics systems. The use of bond graph for modeling electrical and mechanical systems can be found in many areas (Gawthrop, 1991; Amerongen & Breedveld, 2003; Breedveld, 2004; Karnopp, 2006). Further, Chhabra and Emami developed an alternative modeling scheme for mechatronics systems by combining bond graph and block diagram and presented these findings (Chhabra & Emami, 2010). These models hitherto were not used for modeling systems that have logical circuits (that are implemented by chip or transistor). Here we present a way for modeling logical circuits by bond graph that will increase the domain of usage of bond graphs, and they can cover a larger portion of mechatronics systems.

**STRUCTURE OF DIGITAL GATES**

Digital gates are based on the logic rules and the values of inputs, providing what the outputs should be. The logic that is used in these gates is binary logic or 0 and 1, also known as Boolean algebra. In the implementation of these gates each of 0 and 1 values are shown by a domain of voltage (Figure 1) (We use the range that is used in TTL ICs).

The gates that are used and their truth table are shown in Table 1.

As mentioned earlier, the electronic hardware for such mechatronics systems are constructed by transistors or integrated circuits (ICs).

**MODELING GATES BY BOND GRAPH**

Now we want to show these gates by equivalent bond graphs. We show the input of gates, that is a voltage domain, by an effort variable. The input efforts are added to each other and then
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