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Energy Interface for Mixed Reality Design

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Abstract: A unified interface that can seamlessly merge real/virtual spaces or local/remote spaces are presented as a bi-directional energy interface. An arbitrary system consisted of real/virtual objects has some energy connections between the objects of the system. These energy connections can be simply described by bond graphs. Using the mathematical modeling derived from the bond graphs of the system, we can achieve the unified interfaces between the real/virtual objects of the system as well as simulate the real/virtual objects of the system.

We first discuss previous researches about the bi-directional energy interfaces. Next, we briefly review relevant control-theories of modeling physical system and the bond graphs theory as a modern trend of modeling and simulating physical systems. Finally, we introduce the unified energy interface, called *Hyper-Bonds Response Module* (HBRM), and a road map for its implementation.

1. Introduction

With the rapid growth of computer technology and global network infrastructure, nowadays, there are many opportunities and challenges for merging real/virtual spaces or local/remote spaces using the global network. Mixed reality is a field of modern technology mixing real/virtual spaces. It is supported by image integration technology, mixing some virtual 3D graphics and real images, and the physical interface technology between real/virtual objects such as haptic interfaces or tangible interfaces. In many researches [21,20,17,9,26], it has been discussed that physical representations enhance virtual environments. Recently, it is emphasized that the space mixing the real/virtual not only represents one central phenomenon but also represents the periphery with several other phenomena in order to reduce a gap between real/virtual environments [24,25,26]. However, only few studies of the unified interface that relevant physical phenomena—e.g., mechanical force, velocity, temperature, smell, electric and hydraulic—can seamlessly transfer into virtual environment and vice versa, are known.

We note that relevant phenomena, happening in the real environment, are related to energy exchanges. Most physical activities may associated with energy exchanges; e.g., when he or she lifts a bag and puts it on the shelf, he or she has to spend some kinetic energy, and the bag gets the potential energy according to the moved height. Furthermore, the human body is accustomed to feeling and using energy exchanges for his behaviors. Because energy elements such as momentums and displacements can be seamlessly exchanged between real/virtual objects via an energy interface, It is a good candidate for a unified interface that can seamlessly merge real/virtual spaces or local/remote spaces with tight coupling.

Bond graph theory [5], originated by Paynter (1961), is an excellent candidate which can describe energy exchanges between real/virtual objects because of its unified graphical descriptions (effort/flow) for relevant physical phenomena and its re-useable or easily extendable constructions; there are several computer programs such as 20-SIM [30], CAMP [27], MS1 [28], and ENPORT [29], which can simulate the bond graph model. The energy-based approach toward modeling using bond graphs is a modern trend for the design and control of mechatronic systems [12]

Mechatronic engineering is used to control relevant physical phenomena in real environments. In a general way developing a physical linear system using the mechatronic engineering approach, the first process is to mathematically model the behaviors of the system. The second is to design the hardware of the system and the controllers for driving the hardware. The third is to embed the algorithms derived from the mathematical modeling into the controller; arbitrary inputs must be calculated with the algorithms, and then the results must be applied to the controller for driving the actuators such as motor, cylinder, or electric generator to artificially produce the physical phenomena.

The above-mentioned processes have been expanded into the mixed reality physical systems. So far most mixed reality physical systems have supported only one single physical domain for representing the central phenomena and have been developed as one package structure, whose virtual, real, or interface part is inseparable from the system. However, to seamlessly merge the real/virtual environments, it is very important to consider supporting multi-domains and reusable structures. Therefore, Our researches focuses on the unified mixed reality energy interface, that can support multi-domains for representing both central/periphery phenomena, and can easily be reused even if any objects of the system are modified.

2. Previous Researches

The universal energy interface between real/virtual objects was first introduced by Bruns [1], called *Hyper-Bonds* (Fig. 2.1a and Fig. 2.1b); the *power* (effort \times /flow) can be bi-directionally transferred the real into the virtual via the interface and vice versa. It was to open up promising perspectives of further research to merge existing knowledge and tools from various other fields [4]. After that, several researches followed that. In the following part, we historically review the concept *Hyper-Bonds*.

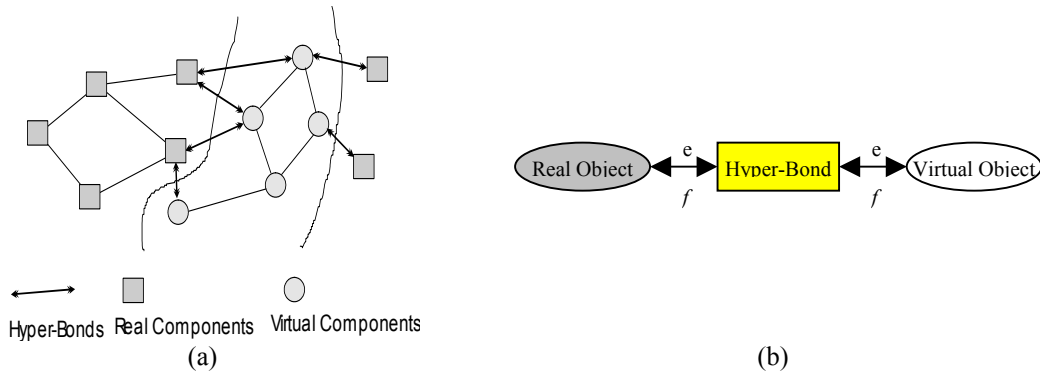


Fig. 2.1 (a) : Boundaries cutting a system [3]
and (b) : Concept of Hyper-Bond

- *Complex Object & Auto-erecting Agents for a Collaborative Learning Environment*

Bruns [1] presented the concept of *complex objects* (Fig. 2.2), having one single real physical part and various virtual parts of different levels of abstraction. Real and virtual parts are coupled by a mechanism of pattern recognition, that may be either grasp-recognition of a sensorised hand like data-glove or by object-recognition with a video-system, sensing the building area. As its prototypes, he showed real construction kits for pneumatics, robotics and conveyor-systems with 3D-VR models based on VRML, special and general application simulators, help-functions and control systems for programmable logic controller.

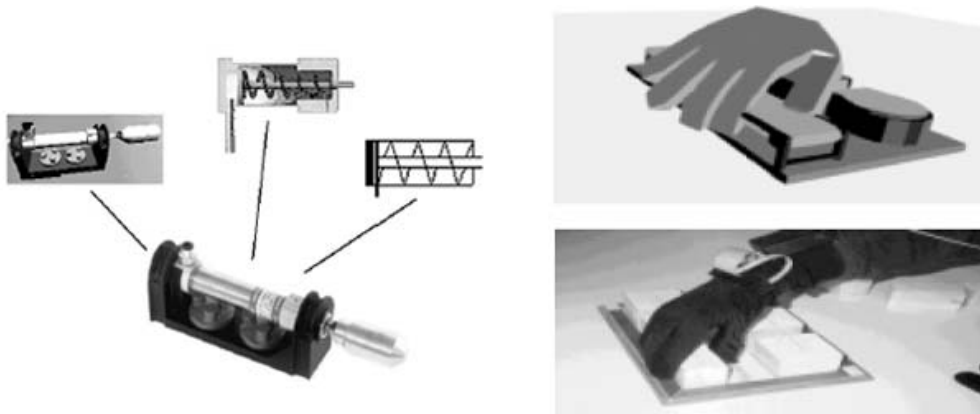


Fig. 2.2 Complex Objects with real tangible parts and various digital representations [2]

This concept was then extended by a *mechanism of auto-erection* (Fig. 2.3), enabling these objects to simulate their own potential environment. To freely mix virtual and real parts on one level of work, each real component is attached a hidden surrounding model, that has links which provide a hidden junction, a source and a sink for this type of physical phenomena and an electrical controllable mechanism to stimulate all input/output behavior of this junction. In the later work, this concept has been changed to a unified approach to connect real/virtual phenomena: *Hyper-Bonds* (Bruns, 2001, 2004)

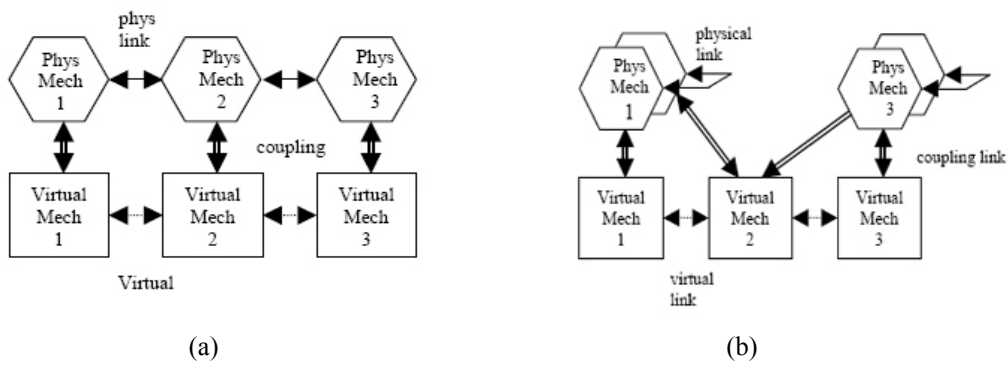


Fig. 2.3 (a) : Links within System Boundaries and
 (b) : Links across System Boundaries [1]

- *A Sensing and Generating Mechanism*

Bruns (1999) presented *a sensing and generating mechanism*, which can switch between source and sink , generate and sense voltage/current- or pressure/volume-flow (Fig. 2.4), supported by bond graph theory. In the multi-domain mixed reality environment, this mechanism allows the bi-directional links mixing real/virtual objects. This mechanism, however, was insufficient for applying to continuous linear time-invariant systems because any methods of switching source and sink for the continuous power transition between real/virtual were not included. Some applications are developed and demonstrated for quasi-static discrete event applications of pneumatic and electrical phenomena¹ (Fig. 2.5).

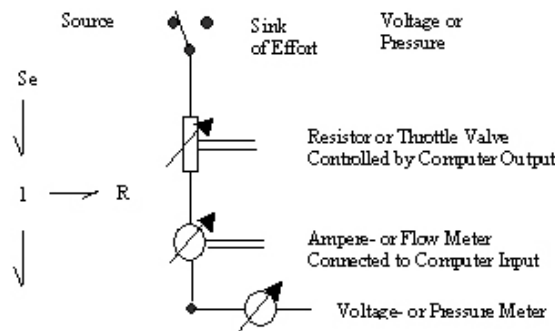


Fig. 2.4 Hyper-Bond for Voltage/Current- or Pressure/Volume-Flow [3]

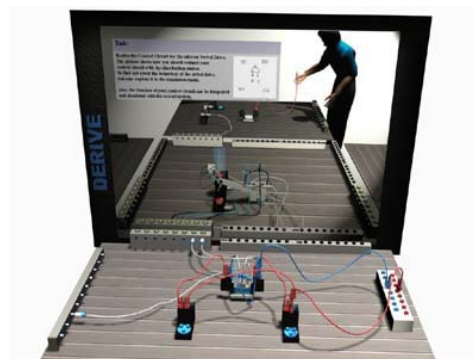


Fig . 2.5 DERIVE Learning Environment¹

¹ EU-IST Project DERIVE (Distributed Real and Virtual Learning Environment for Mechatronics and Tele-Service)

- *Virtual Equivalence*

Yoo (2004) presented the *Virtual Equivalence*, a method to merge real/virtual circuits. In order to bi-directionally connect a virtual electric circuit with a real electric circuit, a virtual circuit in the virtual environment is replaced by an equivalent circuit—this consist of a resistor, capacitor, inductor and voltage source—led by the Thevenin's and Norton's Theorems [16] and physically implemented and connected with the real circuit in the real environment (Fig. 2.6). However, Because of yet unavailable modulating inductance or capacitance by computer and also very restrictive applying Thevenin's and Norton's Theorems to RLC circuits (circuits included resistors, inductors, and capacitors), this method is in difficulties for applying to the complete RLC circuit. Therefore, this method has been applied to only the virtual circuit without capacitors and inductors. It was possible to use a digital potentiometer, which can be controlled by the computer, to implement the equivalent resistance, R_{Th} . As an application with the virtual equivalence, the Framework of the Mixed Reality Breadboard was introduced as Fig. 2.7 [11].

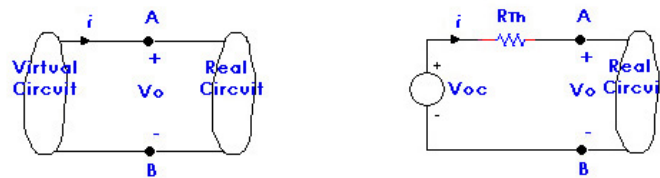


Fig.2.6. Converting the virtual circuit to a virtual equivalent circuit [10]

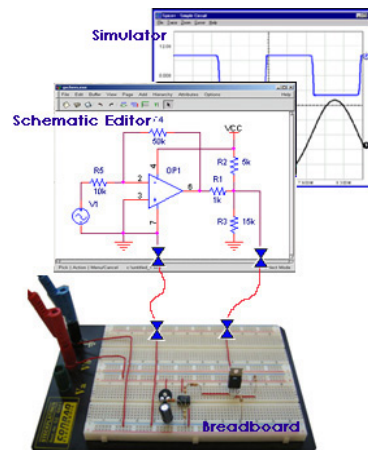


Fig. 2.7 Framework of the Mixed Reality Breadboard [11]

- *Hyper-Bond Subnet (HBS)*

Bruns (2004) presented the *Hyper-Bond Subnet* (Fig.2.8). Given an arbitrary system, any energy connection can be replaced by a HBS conserving the overall behavior and providing a mechanism to separate two physical subnets S1 and S2 connected via HBS, a network of sensors and generators of effort and flow; an arbitrary implementation of S1 and S2 as real or virtual system is possible. This has the advantage that it is not necessary to know anything about the structure of systems S1 and S2. Each Hyper-Bond interface must have a HBS. Some example applications using HBS was simulated with bond graphs [4].

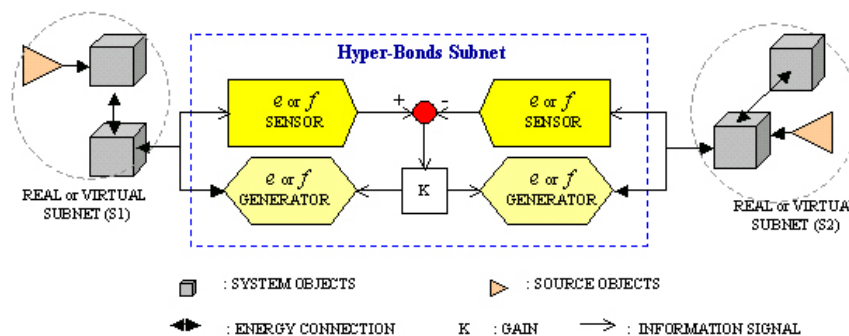


Fig. 2.8 Concept of Hyper-Bond Subnet

3. Mathematical Modeling of Linear Time-Invariant Systems

- *Classical Control Theory*

In order to design, analysis and implement the physical linear system, the system should be mathematically modeled, and such methods have been studied in control system field. Using the state-variable method, linear and nonlinear systems, time-invariant and time-varying systems, and single-variable and multi-variable systems can be modelled in a unified manner. In example Fig. 3.1, this state-variable method is briefly reviewed.

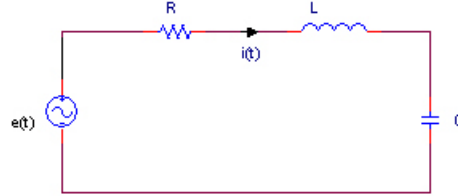


Fig. 3.1 a RLC circuit

This electrical circuit (Fig. 3.1) can be mathematically modeled two equations as follows,

$$C \frac{de_c(t)}{dt} = i(t) \quad (3.1)$$

$$L \frac{di(t)}{dt} = -e_c(t) - Ri(t) + e(t) \quad (3.2)$$

These equations are called first-order differential equation, and the general form is n^{th} -order differential equation such as Eq. (3.3)

$$\begin{aligned} \frac{d^n y(t)}{dt^n} + a_{n-1} \frac{d^{n-1} y(t)}{dt^{n-1}} + \dots + a_1 \frac{dy(t)}{dt} + a_0 y(t) \\ = b_m \frac{d^m u(t)}{dt^m} + b_{m-1} \frac{d^{m-1} u(t)}{dt^{m-1}} + \dots + b_1 \frac{du(t)}{dt} + b_0 u(t) \end{aligned} \quad (3.3)$$

As the state equation form, Eq. (3.1) and (3.2) can be substituted as

$$x_{1(t)} = \int i_1(t), \text{ and } \frac{dx_1(t)}{dt} = x_2(t) = i(t)$$

$$\frac{dx_1(t)}{dt} = x_2(t) \quad (3.4)$$

$$\frac{dx_2(t)}{dt} = -\frac{1}{LC} x_1(t) - \frac{R}{L} x_2(t) + \frac{1}{L} u(t) \quad (3.5)$$

The general form of n state equations is

$$\frac{dx_i(t)}{dt} = f_i[x_1(t), x_2(t), \dots, x_n(t), u_1(t), u_2(t), \dots, u_p(t)] \quad (3.6)$$

where $i = 1, 2, \dots, n$. The i^{th} state variable is represented by $x_i(t)$; u_r denotes the r^{th} input for $r = 1, 2, \dots, p$. The general output equations can be expressed as

$$y_j = g_j[x_1(t), x_2(t), \dots, x_n(t), u_1(t), u_2(t), \dots, u_p(t)] \quad (3.7)$$

where $j = 1, 2, \dots, q$.

In order to be convenient to simulate and analysis the mathematical model with the computer, the general state equations and output equations can describe as the vector-matrix forms,

$$\frac{dx(t)}{dt} = Ax(t) + Bu(t) \quad (3.8)$$

$$y(t) = Cx(t) + Du(t) \quad (3.9)$$

where A is the system matrix, and B is the input matrix. The state-variable response of the system, described by Eq. (3.8), can be written as Eq. (3.10),

$$x(t) = \Phi(t)x(0) + \int_0^t \Phi(t-\tau)Bu(\tau)d\tau \quad (3.10)$$

where x(0) is the initial condition, and $\Phi(t)$ is the state transition matrix,

$$\Phi(t) = e^{At} = (I + At + \frac{A^2t^2}{2!} + \frac{A^3t^3}{3!} + \dots + \frac{A^k t^k}{k!} + \dots) \quad (3.11)$$

Besides, some software, such as MATLAB or Maple, are very useful for computing the elements of the state transition matrix. computing it [16].

Substituting as the vector form of Eq. (3.12) for Eq. (3.4) and (3.5), it can be written as follows,

$$\begin{bmatrix} \frac{dx_1(t)}{dt} \\ \frac{dx_2(t)}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\frac{1}{LC} & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{L} \end{bmatrix} u(t) \quad (3.12)$$

For instance, if A, as the value of the elements, is such as,

$$A = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix}$$

and when u(t) = 1, the state transition matrix is derived as,

$$\Phi(t) = \begin{bmatrix} 2e^{-t} - e^{-2t} & e^{-t} - e^{-2t} \\ -2e^{-t} + 2e^{-2t} & -e^{-t} + 2e^{-2t} \end{bmatrix}$$

The state-variable response of the system is as follows,

$$x(t) = \begin{bmatrix} 2e^{-t} - e^{-2t} & e^{-t} - e^{-2t} \\ -2e^{-t} + 2e^{-2t} & -e^{-t} + 2e^{-2t} \end{bmatrix} x(0) + \begin{bmatrix} 0.5 - e^{-t} + 0.5e^{-2t} \\ e^{-t} - e^{-2t} \end{bmatrix} \quad t \geq 0$$

In most cases of designing linear time-invariant control systems, the transfer function is very important to analyze the system because the characteristics of system can be investigated with it. After investigating the characteristics, the transfer function can be manipulated to improve the behavior of system. As such some methods, PDC (Proportional Derivative Control), PIC (Proportional Integral Control), PID (Proportional Integral and Derivative Control) are already well-known. The transfer function of the Fig. 3.1 can be derived through the Laplas Transform of the Eq. (3.1) and (3.2), or from the state diagram. Fig. 3.2a is the state diagram from Eq.(3.1) and Eq. (3.2). There are also methods to derive the state diagram from the differential equation (see [22]). Fig. 3.2b is the block diagrams of the transfer functions. The state diagram method is often used for developing the control system, because to derive some the transfer equation from the state diagram is much more easier than to directly derive the transfer equation from the differential equations.

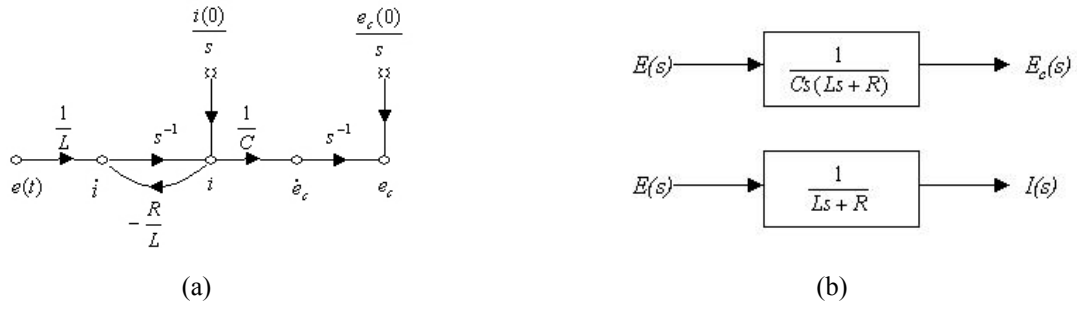


Fig. 3.2 the state diagram (a) and the block diagram (b)

$$\frac{E_c(s)}{E(s)} = \frac{(1/LC)s^{-2}}{1 + (R/L)s^{-1}} = \frac{1}{Cs(Ls + R)} \quad (2.13)$$

$$\frac{I(s)}{E(s)} = \frac{(1/L)s^{-1}}{1 + (R/L)s^{-1}} = \frac{1}{Ls + R} \quad (2.14)$$

The general form of Eq. (3.13) or (3.14) can be derived through the Laplas Transform of Eq. (3.3), as following,

$$G(s) = \frac{Y(s)}{U(s)} = \frac{b_m s^m + b_{m-1} s^{m-1} + \dots + b_1 s + b_0}{s^n + a_{n-1} s^{n-1} + \dots + a_1 s + a_0} \quad (3.15)$$

So far, some methods to mathematically describe the system is introduced, and those have some relationships for the conversion among various, it shows in Fig. 3.3,

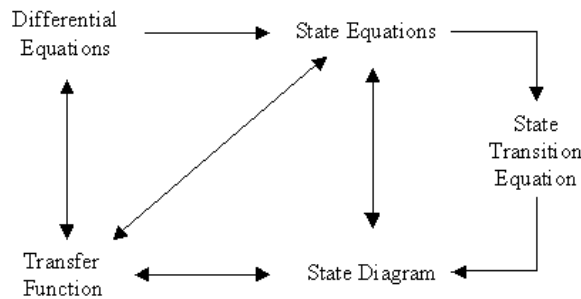


Fig. 3.3 showing the relationships among various methods of describing linear systems [22]

The above-introduced methods can be applied to various domains of control systems, e.g., mechanical system, hydraulic systems, electrical system, acoustical system, and thermodynamic system. Meanwhile, If we consider some multi-domain system, e.g., an electrical and mechanical system, a hydraulic and mechanical system, it may be much more complex to derive the mathematical models than the single domain system because many state variables from the different domains must be considered.

- *Bond-Graphs Theory*

The Bond-graphs, originated by Paynter (1961), are a domain-independent graphical description of dynamic behavior of physical systems. Different domains can be described in the same way, and its physical concepts are based on energy and energy exchange. One of the most important advantage of the bond graph modeling is that the bond graphs have all information to derive the set of state equations, and there is some bond graph software like 20-sim (Broenink, 1990), CAMP (Granda, 1985), MS1 (Lorenz, 1997), Enport (Rosenberg, 1074), which can simulate the bond graph model and derive the state equations.

In physical systems, an interaction between subsystems is always coupled to an exchange of energy, and such a relation is called a power bond. Places at which power can flow between subsystems are called ports, and physical subsystems with one or more ports are called multiports. Fig. 4 shows a bond connection two ports. To describe power interactions of all types of multiports in a common language, effort and flow are described as the universal power variables, and its several types of power interchange shows Table 1. Therefore, the power $P(t)$ is expressed as the product of an effort and a flow variable, as Eq. (3.16). And the $e(t)$ and $f(t)$ are related with the energy variables, momentum $p(t)$ and displacement $q(t)$, such as the Eq. (3.17).

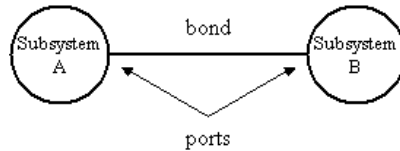


Fig. 3. 4 Bond connection two ports

$$P(t) = e(t) \cdot f(t) \quad (3.16)$$

$$\frac{dp(t)}{dt} = e(t), \quad \frac{dq(t)}{dt} = f(t) \quad (3.17)$$

Domain	Effort, $e(t)$	Flow, $f(t)$
Mechanical translation	Force component, $F(t)$	Velocity component, $V(t)$
Mechanical rotation	Torque component, $\tau(t)$	Angular velocity component, $\omega(t)$
Hydraulic	Pressure, $P(t)$	Volume flow rate, $Q(t)$
Electric	Voltage, $e(t)$	Current, $i(t)$

Table 3.1. Some Effort and Flow Quantities [5]

Fig. 5 is the bond graph symbol from Fig. 4; The half arrow on a port line indicates the direction of power flow at any instant of time when the effort and flow variable both happen to be positive.

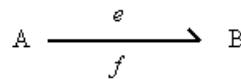


Fig. 3.5 Bond graph symbol without causal stroke

The causal stroke must be added to the symbol of Fig. 3.5 to determine the computational direction of the variables. For example in Fig. 3.6a, the effort from subsystem A is the input of subsystem B, and the flow from subsystem B is the input of subsystem A. Fig.3.6b is vice versa.

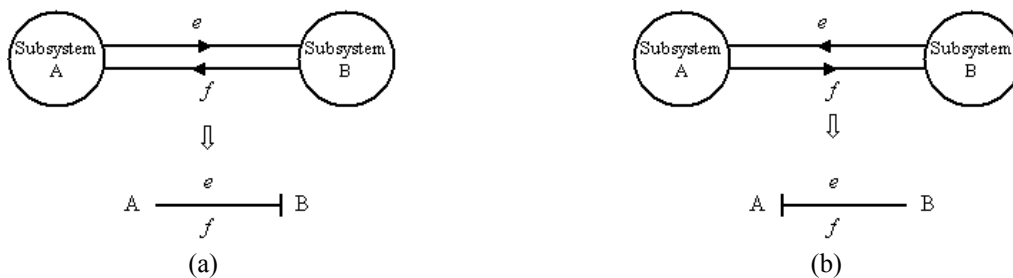


Fig. 3.6 the meaning of causal strokes

Type	Elements	Explanations or Examples
R	storage	electric resistor, mechanical friction
C	storage	capacitor, spring
I	resistor	inductor, mass
Se Sf	sources	electric sources, gravity, pump
TF	transformer	electric transformer, toothed wheels, lever
GY	gyrator	electromotor, centrifugal pump
0	0-junction	common effort
1	1-junction	common flow

Table. 3.2 Type of bond graph elements [6]

In Fig. 3.7, the tetrahedron of state according to the variables they relate give us an insight into understanding some physical phenomena related with three elements. In addition, in the linear system, momentum q is $C \cdot e$, displacement p is $I \cdot f$, and e is $R \cdot f$ in the linear system or the non-linear system.

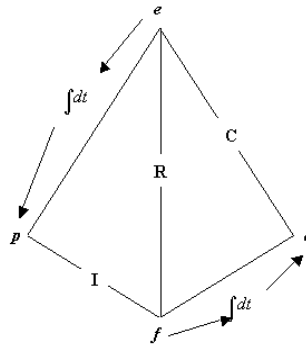


Fig. 3.7 the tetrahedron of state [6]

As an example of the bond graphs, the electronic system Fig. 2.1 is modeled in Fig. 3.8, and its equations are as follows,

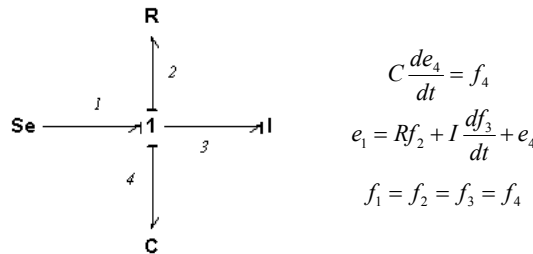


Fig. 3.8 a bond graph modeling

These equations are the same as Eq. (3.1) and (3.2), and its vector-matrix form is also the same as Eq.(3.8). It is notable that the bond graphs have very simple constructions to derive the state equations. With bond graph software like 20-SIM, the state equations can be directly computed.

4. Unified Energy Interface for Mixed Reality Physical System

- Hyper-Bonds Response Module (HBRM)

In an arbitrary physical system having some energy connections between the objects of the system, assuming that one classifies the physical system into two parts and replaces one parts of the two by its virtual simulations, a *Hyper-Bonds Response Module (HBRM)* can achieve the energy interfaces between real objects and the virtually simulated objects. A HBRM consist of a *Response Function Set (RFS)*, *sensors* and *generators*.

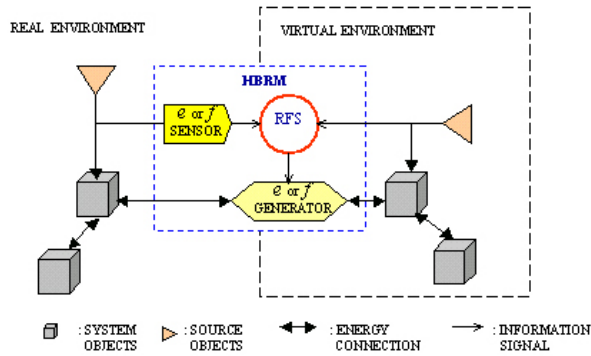


Fig. 4.1 Concept of HBRM

RFS (Response Function Set) – is solution algorithms of the state equation set of the system before replacing some parts of the system by its virtual simulations. As reviewed in the part 3, the state equation set is a mathematical modeling of the linear system, and it can be simply derived from the bond graphs of the system. An arbitrary system can be simulated by the computer using the solution algorithms of the state equation set. Therefore, after replacing any parts of the system by its virtual simulations, all behaviors of the system can be simulated by the computer using the RFS. For instance, Fig. 4.2 shows a physical system which has some energy connections between the objects. If its any parts are replaced by virtual simulations, all behaviors of the mixed reality physical system can be simulated by the computer using its RFS as Fig. 4.3.

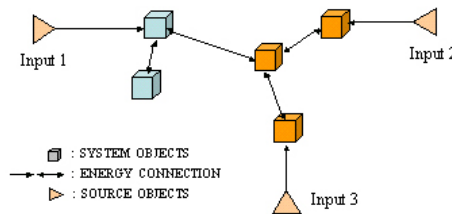


Fig. 4.2 The energy connections of a physical system before replacing some parts by its virtual simulations

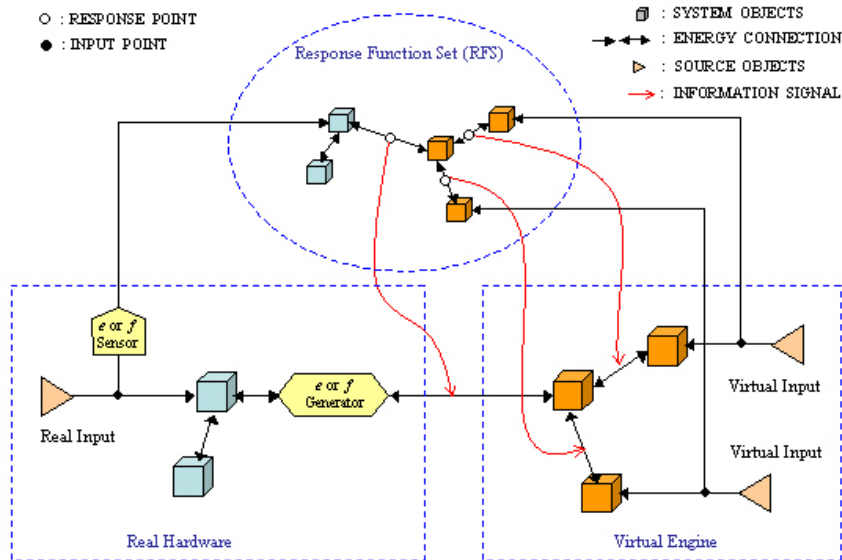


Fig. 4.3 Simulating the system after replacing the parts by its virtual simulations

effort or flow Sensors – sample the inputs of the system and transfer the input signals to the RFS: effort sensor can be electric voltage sensor, air pressure sensor, force sensor or temperature sensor etc, and flow sensor can be electric currency sensor, air volume flow sensor, velocity sensor and heat-flow sensor etc.

effort or flow Generators – bi-directionally generate the physical outputs, simulated by the computer using the RFS: effort generator can be electric voltage generator, air pressure generator, force generator or heat generator etc, and flow generator can be electric currency generator etc.

- Local and Distributed

We consider two cases, local mixed reality system and distributed mixed reality system using the internet. In order to apply the HBRM to both cases, it is necessary to define these two.

Local Mixed Reality System – consist of real part having physical representations, a HBRM, virtual input generators, a graphic engine displaying virtual objects and TCP/IP communication for connecting the other mixed reality local systems (Fig. 4.3).

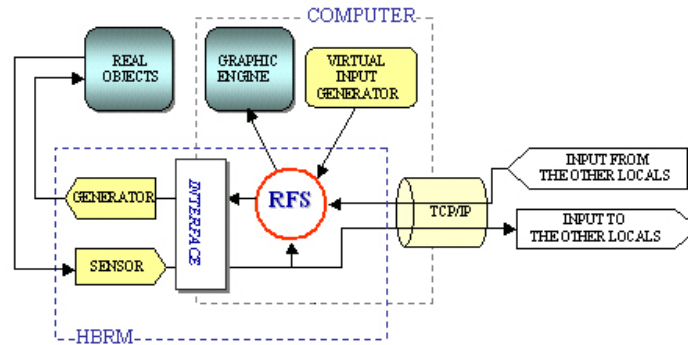


Fig. 4.3 local mixed reality system using a HBRM

Distributed Mixed Reality System – consist of more than two local mixed reality systems. In this case, all local mixed reality systems have the same RFS. All real and virtual inputs must be simultaneously shared with all local systems. In perspective, it is possible to immediately recompose the distributed mixed reality system. Fig. 4.6 shows a distributed mixed reality system and its recombination aspect

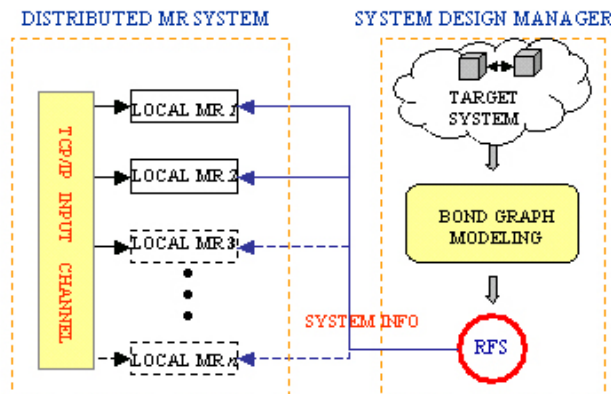


Fig. 4.6 distributed mixed reality system and reusable aspect

- Road Map of Designing Unified Energy Interfaces

We present five steps to the road map of designing unified energy interface. With a following example, this road map is described in detail

Step 1. Describe the physical system using the bond graphs, before classifying it into real/virtual parts.

Step 2. Derive the state equation set of the physical system from the bond graphs—use the bond graph software like 20-SIM.

Step 3. Classify the system into real/virtual parts, and define input/output interfaces in the bond graphs—ports of all source objects are input interfaces; all boundary ports between real/virtual objects are output interfaces.

Step 4. Produce the RFS of the input/output interfaces from the state equation set, and embed the produced RFS in the local mixed reality.

Step 5. Compose a local mixed reality system consisted of a HBRM in which the RFS is embedded, a graphic engine, a virtual input generator and a TCP/IP communication—the graphic engine of the local mixed system must be able to appropriately display behaviors of the virtual objects using the results of the RFS; sensors/generators modules must be designed according to the needs of the system.

Now, we apply this road map to Fig. 1. In step 1, Fig. 3.1 can be described using bond graphs as Fig. 4.4.

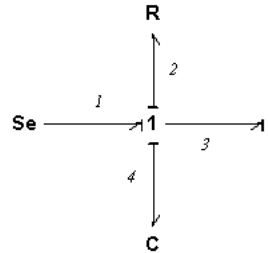


Fig. 4.4 Description using bond graphs

In step 2, the state equation set of the system is generated by bond graph software (20-SIM) as

dynamic equations:
 $C1\backslash p.f = I2\backslash state / I2\backslash i;$
 $C1\backslash p.e = C1\backslash state / C1\backslash c;$
 $R1\backslash p.e = R1\backslash r * C1\backslash p.f;$
 $OneJunction1\backslash p3.e = Se1\backslash p.e - R1\backslash p.e;$
 $I2\backslash p.e = OneJunction1\backslash p3.e - C1\backslash p.e;$

system equations:
 $I2\backslash state = \text{int} (I2\backslash p.e, I2\backslash state_initial);$
 $C1\backslash state = \text{int} (C1\backslash p.f, C1\backslash state_initial);$

The above results equal Eq. (3.8). In step 3, this system can be classified as two parts such as Fig. 4.5. The port 1 is the input interface port, which should be connected with a voltages sensor. The port 3 is a output interface port, which should be connected with a voltage generator and the graphic engine, because of the boundary port between the real and the virtual. There not exist any virtual inputs. The port 4 and 5 are the output interfaces to the graphic engine.

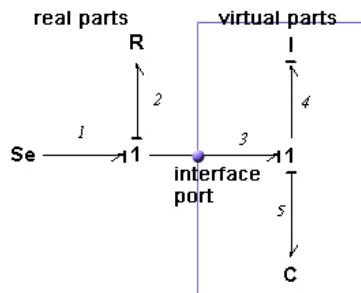


Fig. 4.5 Classify the real/virtual ports

In step 4, its RFS can be expressed as

$$RFS_v[x_1(t), x_2(t), u_1(t)] \quad (4.1)$$

where v set express the number of the output interfaces defined in step 2; x is the state variable; u is input variable. In step 5, a local mixed reality system consisted of a HBRM in which the RFS is embedded, a graphic engine, a virtual input generator and a TCP/IP communication must be composed.

References

- [1] Bruns, F. W., Gathmann, H. (1999): Auto-erecting Agents For a collaborative Learning Environment – Proc. IEEE 8th Int. Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises, Stanford
- [2] Bruns, F. W. (1999): Complex Construction Kits For Coupled Real and Virtual Engineering Workspaces – Norbert A. S. Streitz et al (1999): Lecture Notes in Computer Science 1670. Springer, Berlin, pp 55-68
- [3] Bruns, F. W. (2001): Hyper-Bonds (Enabling Mixed Reality) – artec-paper 82, Bremen
- [4] Bruns, F. W. (2004): Hyper-Bonds (Applications and Challenges) – artec-paper 115, Bremen
- [5] Paynter, H. M. (1961). Analysis and Design of Engineering Systems, MIT Press Cambridge, MA
- [6] Karnopp, D. C., D.L. Margolis, R.C. Rosenberg (1990). System Dynamics – A unified Approach. John Wiley, New York
- [7] Ohta, Y., H. Tamura (1999): Mixed Reality – Merging Real and Virtual Worlds. Tokyo
- [8] Yoo, Y., Bruns, F. W. (2004): Realtime Collaborative Mixed Reality Environment with Force Feedback. Proc. 7th IFAC Symposium on Cost Oriented Automation, Ottawa
- [9] Yoo, Y., Bruns, W. (2004): Motor Skill Learning with Force Feedback in mixed Reality. 9th IFAC Symp. on Analysis, Design, and Evaluation of Human-Machine Systems, Atlanta
- [10] Yoo, Y. (2004): Bi-directional Mixed Reality Electric Circuit (Virtual Equivalence) – artec-paper 114, Bremen
- [11] Yoo, Y.H., Bruns, F. W. (2005): Bi-directional Energy Interfaces for Mixed Reality Design — A Support for Collaborative Engineering —. 16th IFAC World Congress, Prague, July 3-8
- [12] Amerongen, J., Breedveld, P. (2004): Modelling of Physical Systems for the Design and Control of Mechatronic Systems – IFAC Professional Brief
- [13] Faust, M., Bruns, F. W.(2003): Mixed Reality Web Service."Air through the Internet"—Technology Enhanced Learning '03 (TEL'03), Milano
- [14] Jan, F. Broenick (1999): Introduction to Physical Systems Modelling with Bond Graphs – University of Twente, Netherlands
- [15] Jose J. Granda, Raymond C. (2003 ?): Automated Modeling and Simulation Using the Bond graph Method for the Aerospace industry
- [16] Hannes, G.(2003): Control Systems Analysis Using MATLAB — National Technical University of Athens
- [17] Basdogan, C., C.-H. Ho, M. A. Srinivasan. (2000). An Experimental Study on the Role of Touch in Shared Virtual Environments. *ACM Transactions on Computer-Human Interaction*, **7**, (4), pp 443-460
- [18] Dunne, A. and Ragy F. Fields and Thresholds. Presentation at th Doors of Perception 2, November 1994, <http://www.mediamatic.nl/Doors/Doors2/DunRab/DunRab-Door2.html>
- [19] Iwata, H., Fell-through: Augmented Reality with Force Feedback, in Mixed Reality Merging Real and Virtual Worlds, Y. Ohta and H. Tamura, Editors. 1999, Ohmsha, Ltd. Tokyo. P. 215-227.
- [20] Ishii, H. and Ullmer, B, Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms, Proc. CHI 97, pp 234-241, ACM Press, 1997.

- [21] Eva-lotta, S., Kirsten, R., Calle, S. (2000) : Supporting Presence in Collaborative Environments by Haptic Force Feedback, *ACM Transactions on CHI*, Vol. 7, No.4, p 461-476
- [22] Benjamin C. K. (1995) : *Automatic Control Systems*, Prentice-Hall International Inc.
- [23] Don H. Johnson : *Origins of the Equivalent Circuit Concept*, Rice University, MS366, Houston, TX77251
- [24] Weiser, M., and Brown, J. S. : *Designing Calm Technology*. <http://www.ubiq.com/hypertext/-weiser/calmtech/calmtech.htm>, December 1995.
- [25] Weiser, M. *The Computer for the 21st Century*. *Scientific American*, 1991, 265 (3), pp.94-104
- [26] Dunne, A. and Raby F. *Fields and Thresholds*. Presentation at the *Doors of Preception 2*, November 1994, <http://www.mediamatic.nl/Doors/Doors2/DunRab/DunRab-Doors-E.html>
- [27] Granda, J.J. (1985), Computer generation of physical system differential equations using bond graphs, *Journal of the Franklin Institute*, vol 319, no 1/2, pp 243-256
- [28] Lorenz, F. (1997), *Modelling System 1*, users manual, Lorenz Simulation, Liege, Belgium
- [29] Rosenberg, R.C. (1974), *A user's guide to ENPORT-4*, Wiley, New York.
- [30] Broenink, J.F. (1999), 20-SIM, software for hierarchical bond-graph / block-diagram models, Submitted to *Journal Simulation in Practice and Theory*.

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bildet eine experimentelle Gruppe von Wissenschaftlern, Ingenieuren und Künstlern.

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Wir experimentieren mit der Vermischung von realen und virtuellen Welten an der Grenze zwischen maschineller Funktion und menschlicher Phantasie.

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Der Mixed Reality Ansatz eröffnet neue Sichtweisen.

Wir modellieren mit realen Gegenständen, die eine reiche sinnliche Erfahrung mit der Widerspenstigkeit realer Phänomene vermitteln.

Wir formen virtuelle Gegenstände, die vielfältige Übersetzungen zwischen konkreten und abstrakten Sichtweisen realisieren.

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4. Micado, Projektbericht des studentischen Projekts micado zu Mixed Reality Caves
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6. Micasa, Projektbericht des studentischen Projekts micasa zu Mixed Reality Caves
7. Bernd Robben, Ralf Streibl, Alfred Tews, Mixed Reality Adventures, Bericht vom Symposium im Kino 46
8. Daniel Cermak-Sassenrath, Martin Faust, Computerspiele