Patients waiting for a heart transplant often need to bridge the time until surgery. This is usually done using implantable pumps. To develop the control algorithms for these artificial hearts, researchers at the University of Queensland modeled the human vessel system on the PC and connected it to an artificial heart.

The pulsatile (i.e., rhythmically pumping) artificial hearts available today have some serious disadvantages. They wear out quickly (after a maximum of one year), have a high energy consumption, and are relatively large so they can be implanted in only about 75% of men, a far lower number of women, and not in children. Rotary pumps, which provide a continuous blood flow, have many advantages over pulsatile pumps, because they are smaller by design, more durable and energy-efficient. Therefore, researchers use the rotary blood pump technology to develop novel artificial hearts. To give artificial hearts the ability to automatically adapt their pumping power to changing needs in the blood flow (for exercise or sleep, for example), the developers need a powerful test environment that can imitate the human vascular system in all situations.

Virtual Blood Vessels on the PC

Until now, a setup of tubes, pipes, valves, and pressure transducers was

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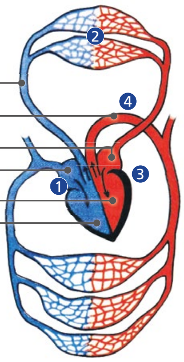
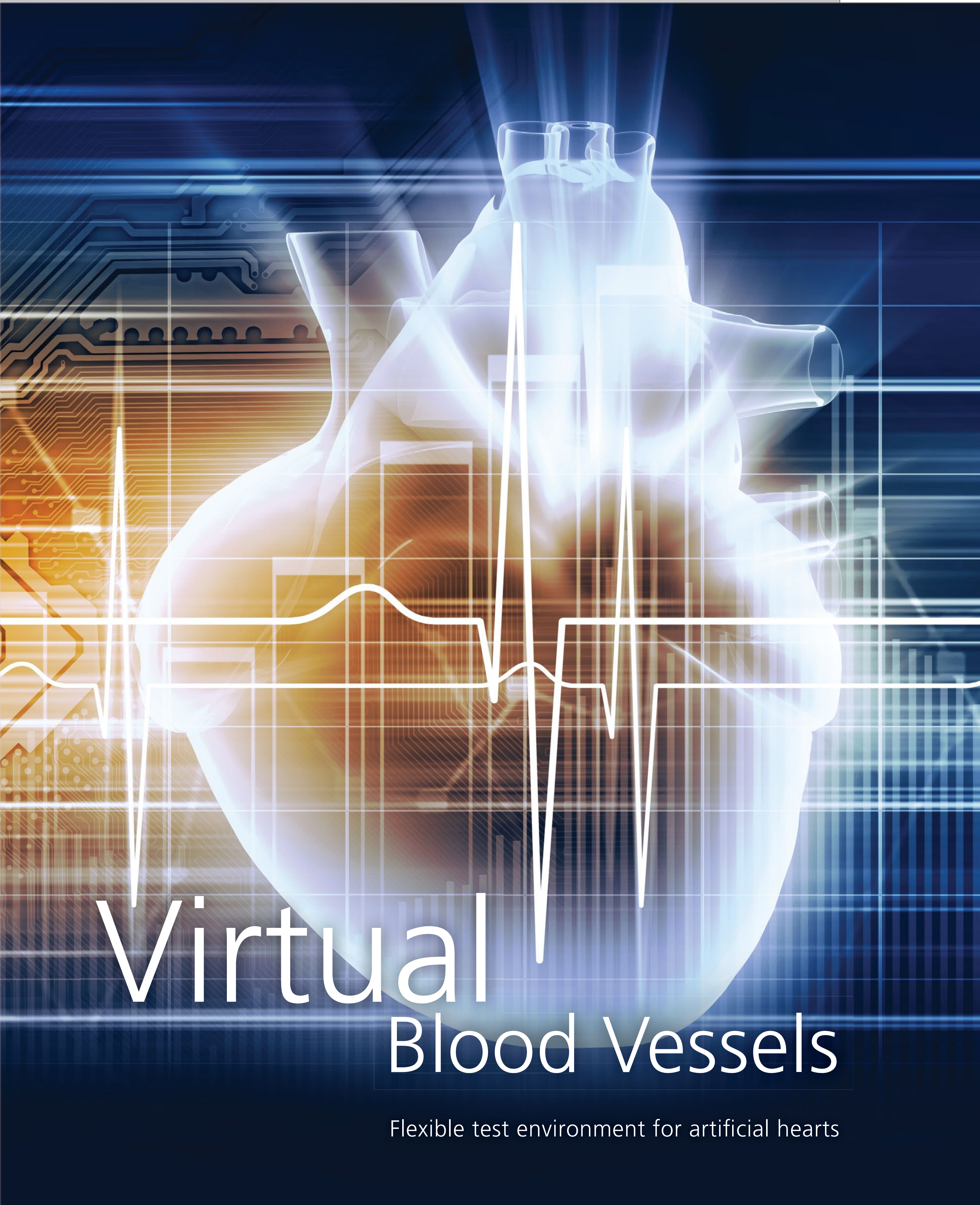
Figure 1: Simplified representation of blood circulation in a healthy cardiovascular system. The blood supply to the different body regions adapts to the changing local needs by varying pulse, pumping power and blood vessel contraction.



Path of the Blood Through the Body:

1. The body's deoxygenated blood (shown in blue) flows through the right atrium to the right ventricle. Then it is pumped into the lungs via the pulmonary artery.
2. In the lungs, carbon dioxide is removed from the blood and the blood is oxygenated.
3. The oxygenated blood (shown in red) flows through the left atrium into the left ventricle.
4. The left ventricle pumps the blood through the aorta and to all organs to supply them with oxygen. This process is then repeated.



Virtual Blood Vessels

Flexible test environment for artificial hearts

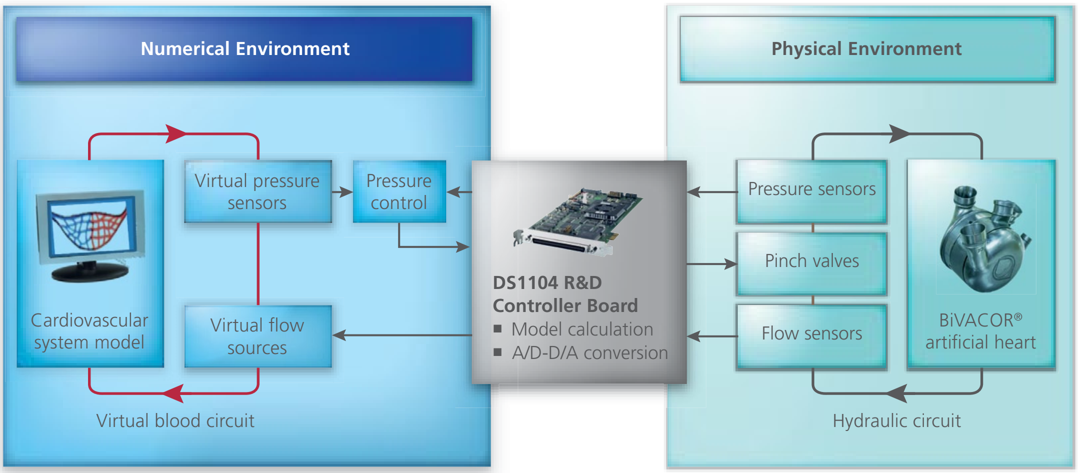
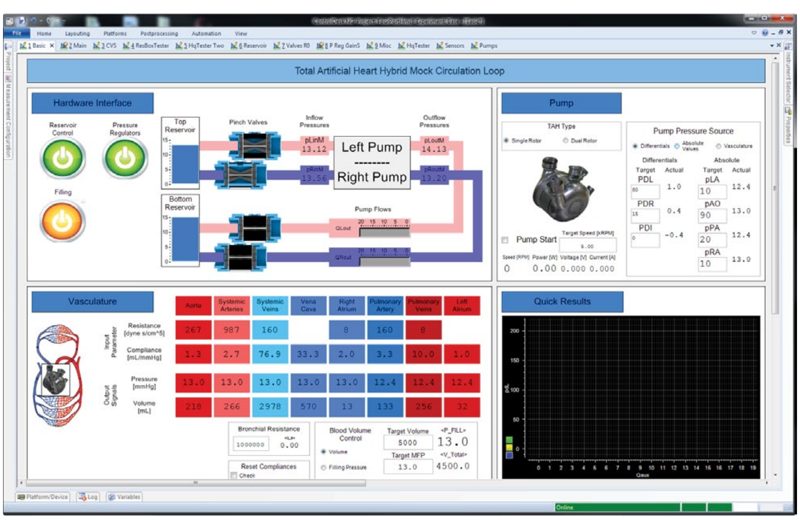


Figure 2: Schematic setup of the test bench. The blood vessel system modeled on the PC is connected to the artificial heart by various sensors and actuators. The properties of the blood system can therefore be changed easily.

needed in order to realistically simulate the human vascular system and its characteristics in the lab. But the many hydraulic and mechanical components make these setups very complex and not flexible enough. This is why researchers at the University of Queensland have embarked on a different path (figure 2). They modeled the entire vessel system as a numerical model on a standard PC, which was expanded with a DS1104 R&D Controller Board to control all experiments. The artificial heart is connected with a simple tube system to build a hydraulic cycle. A glycerin/water mixture is fed into the system to simulate blood because its fluid characteristics are identical to those of human blood.

Figure 3: The dSPACE experiment software ControlDesk Next Generation provides the central user interface and serves to record data, change parameters, and graphically displays different system states.



Flexible Test Environment for Artificial Hearts

Pressure and flow sensors and several pinch valves at the tubes act as the interface between the vasculature model on the PC and the mechanical artificial heart. The pinch valves control the flow of the mock blood so that it equals the flow of real blood in the human vascular system. The properties of the vascular system (e.g., the compliance of the vessels) are easily changed on the PC, so different scenarios can be simulated conveniently, such as a still or moving person. This allows for comprehensive tests of the control algorithm of the artificial heart.

Testing Artificial Hearts with dSPACE Equipment

The (pressure and flow) sensors and actuators (pinch valves) are connected to the dSPACE DS1104 board installed on the PC. The dSPACE experiment software ControlDesk Next Generation was used to develop

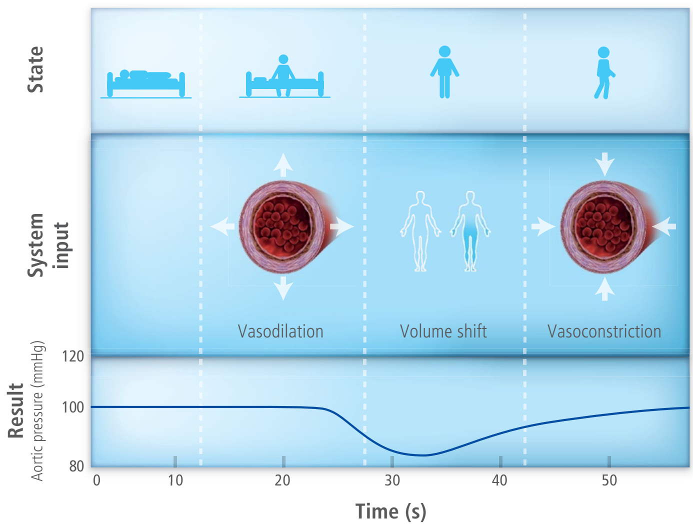


Figure 4: During the simulation of a person standing up, the aortic pressure curve of the artificial cardiovascular system reacts just like a human organism.

the central user interface (figure 3). The software serves to record data, change parameters (such as the resistance and compliance of the blood vessels), and graphically displays the different system states. The cardiovascular model and the control algorithms for the artificial heart were developed in MATLAB®/Simulink® and executed with a step width of 1 ms.

Simulating Everyday Scenarios

An everyday situation demonstrates how powerful the setup is: If a person stands up, the systemic resistance drops due to muscular activation. While the person moves from a lying to a standing position, fluid moves from the thorax into the lower limbs (volume shift downwards). As a reaction, the vessels start to constrict, the resistance recovers and settles at a higher value than before. Finally, the muscle pump effect in the legs helps to redistribute fluid (volume shift upwards). This is how the organism avoids dizziness and fainting when a person stands up.
In order to replicate this process, the sequence was programmed into the simulation model (figure 4). Fluid shifts were caused by changes in compliance, while vasodilation and constriction were imitated by different resistance values. The resulting temporal behavior of the simulated blood pressure matches the processes in the human organism. ■

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> "With the dSPACE system we were able to build a flexible and efficient development environment for the BiVACOR artificial heart."

Frank Nestler, University of Queensland

Conclusion

The dSPACE tools were used to build a test environment for artificial hearts in which the artificial heart is the only remaining mechanical component. Because the entire human vessel system was modeled on the PC, its characteristics can be altered conveniently and quickly. This development environment makes it possible to create reproducible (automatic) tests for artificial hearts under different requirements.
With this procedure, developing control algorithms has become much easier.

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