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Design, Construction, and Testing of a Novel Robotic Workstation

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Abstract

This paper describes the development of a novel robotic workstation which users configure to a variety of spatial forms. These configurations allow users to define their physical workspace as well as to situate computer and analogue tools precisely to support a broad range of work-and-leisure computing activities. The workstation is part of our Animated Work Environment (AWE) project aimed at programmable smart environments which fundamentally alter user experience. This paper describes, in detail, the design, realization, and initial testing of the multi-panel robot workstation which itself represents a novel type of robot surface.

Keywords: robotics, animation, human-robotic interaction, intelligent environments

1 Introduction

In an increasingly "digital" society, many of our everyday activities are becoming more efficient, stream-lined, and complex due to the wide-spread adoption of mobile Information Technologies [IT]. People can answer e-mails, search the internet, record media such as audio files, photographs and videos, and edit documents on-the-move, using relatively inexpensive cell phones, PDAs and laptop computers – portable devices easily synchronized. But while Information Technologies have greatly expanded the mobility of computing, it has not offered as much to the relatively static, fixed work environments residing within our workplaces and homes. Here, printed materials and computer peripherals still clutter desks, while traditional furniture and lighting crowd rooms. A different kind of workplace incorporating intelligent, reconfigurable elements promises to better adapt to an increasingly digital world, allowing computer users to become more efficient, more organized, and potentially more creative.

Upon first approach, the robot workstation introduced in this paper appears to be nothing more than a flat wall (Figure 1). When the user takes control it transforms into a personalized, intimate space for the focused composing of documents (Figure 2); or, alternatively, a configuration designed for presenting to an audience (Figure 13a). The workstation efficiently utilizes space by dramatically transforming itself to match the needs and wants of different users. Computing, digital projection, and lighting will emanate from within the workstation itself.

The design concept is not limited to the office. The workstation can function inside distinct rooms of different sizes and purposes because it can adapt its physical form. At home, for instance, the workstation supports home-office tasks; when these tasks are accomplished, the system provides configurations suited to online gaming (Figure 13b), shopping, viewing, tutoring, and creative/investigative activities.

The concept of a dynamically reconfigurable, intelligent environment is the focus of the larger *Animated Work Environment* (AWE) research project [1], [2]. The multidisciplinary research team is comprised of investigators in Architecture, Robotics, Sociology, and Psychology. In the first year of research, the Sociologists conducted detailed phone surveys of technology users while the Psychologists performed task analyses of a range of subjects chosen to represent a large spectrum of workers performing everyday tasks within their physical work environments [3]. These efforts helped the team identify the needs and wants of workers with respect to the physical environments in which they routinely perform their work. The results strongly support the need for embedded IT within a physical environment that is both intelligent and readily reconfigurable.

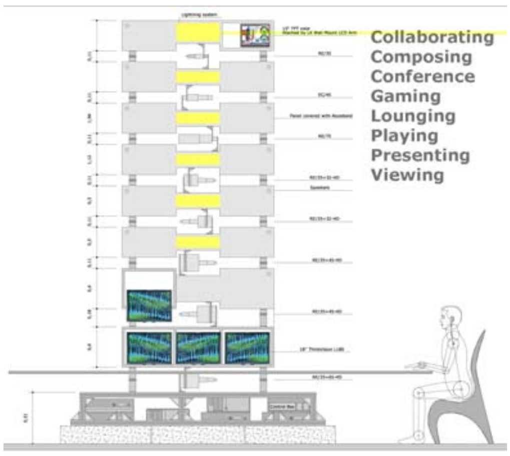

Figure1: Workstation design as a flat wall

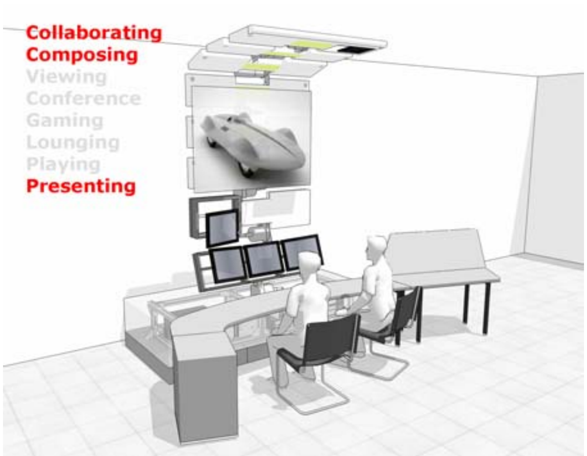

Figure 2: Preliminary workstation design configured for "collaborating and composing."

Based on the outcomes of these ethnographic studies, the Architects and Engineers, with continued input from the social scientists, designed the workstation concept shown in the first figure. The basic design features multiple "smart panels" which fold and unfold to enable the desired environments. Once the concept was accepted by all members of the research team, the details of realizing a physical, full-scale, working prototype began. This paper describes, in detail, the four key aspects in developing the workstation prototype: its basic design, hardware realization, control issues, and initial testing.

2 Background and Previous Work

The concept of robot systems based on serial arrangement of rigid elements is not new. Traditional rigid-link manipulators have been successfully deployed in numerous applications, and are well understood by the robotics community [4]. What noticeably differentiates the AWE workstation introduced in this paper from traditional robot structures is that its profile is two-dimensional. In other words, it is a reconfigurable surface instead of one-dimensional "backbone drawn in space". Additionally, unlike conventional robots, the AWE workstation features redundant degrees of freedom. This kinematic redundancy will allow the robot to retain the position of a panel while changing the configuration of the rest of the robot [5]. This is critical, for example, when the user desires to maintain a display or lighting orientation while reconfiguring the system.

Kinematic redundancy has been an important research area in robotics in the last few years. There are numerous examples of redundant robot manipulator arms in the literature [5],[6]. Snake-like robots [7] also feature significant redundancy. Some of the algorithms for motion planning of redundant systems developed in the literature will be applicable to the kinematically redundant AWE workstation. However, the AWE workstation is novel with respect to state of the art robots due to its surface-like nature and its environment. Unlike redundant manipulators, *the entire body* – not only the end effector – is important in the user task. Unlike typical snake-like applications, the vertical plane is a key factor in design considerations, given gravity's impact on the system.

The AWE workstation is also novel within the discipline of Architecture. The use of programmable links, let alone robotics, to "activate" architectural spaces has seldom been explored by architects—even as William Mitchell envisions the architecture of the near future as "robots for living in" [8]. IT embedded in architectural works has mostly been for purposes of information display and environmental control. One notable exception is the programmable, flexible spaces framed by continuum structures developed by the "*Hyperbody Research Group*" of Kas Oosterhuis at the Technical University of Delft [9]. The *Hyperbody* investigation, constructed of off-the-shelf computer-controlled bladder elements, is not a novel multi-panel system and is not intended to support routine, everyday tasks as is the workstation presented here. The AWE workstation is also novel for IT investigators concerned with supporting work practices frequently defined as *Computer-Supported Collaborative Work* [CSCW]. CSCW research focuses not on robotics but mostly on computer displays and whiteboards to create electronic meeting rooms [10]. Sharing many of our own ambitions, the *Roomware* project is exemplary for creating an embedded IT work environment, but one without robotic elements [11]. Compared to these efforts in IT and Architecture, the workstation presented in this paper is novel as a configurable robot-environment supporting working life in an increasingly digital society.

3 Workstation Design/Realization

In this section, we detail the design and realization of a first prototype of the AWE workstation concept.

3.1.1 Overall Multi-Panel Design

The initial prototype is a multi-panel structure, folding within a plane. The panels have the ability to fold, enabling a rich variety of work and leisure environments, and unfold to create a flat surface. Initial analysis suggested that eight panels and eight degrees of freedom would be sufficient to provide the variety of configurations desired for testing. After the detailed dimensions were defined, the design was simulated in the modelling program, SolidWorks (Figure 3). Aluminium was chosen as the material for panel construction, due to its light weight. Based on the weight of aluminium, calculations were made to determine the weights of each of the panels and the system overall.

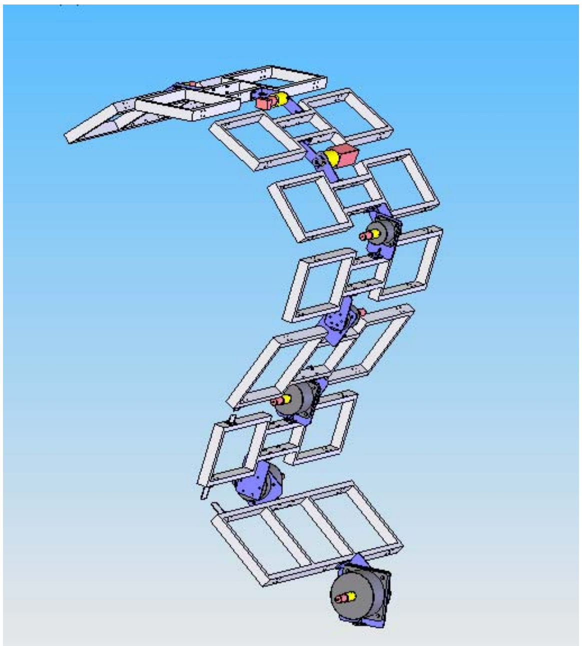

Figure 3: AWE prototype design shown in SolidWorks

3.1.2 Actuator/Transmission Selection

Conventional electric motors were chosen for the workstation's actuators and are located adjacent to each panel (Figure 3). This was due in part to the resulting simplicity and modularity of design, compared with alternative remotely-actuated tendon-based designs.

Specific motors were selected for each panel. One of the key criteria in this choice was the extreme torque requirements required to move the panels. These torques were calculated at the worst-case load scenario, where the entire workstation was configured horizontal to the ground, making the center-of-gravity as far as possible from each respective motor (Figure 4).

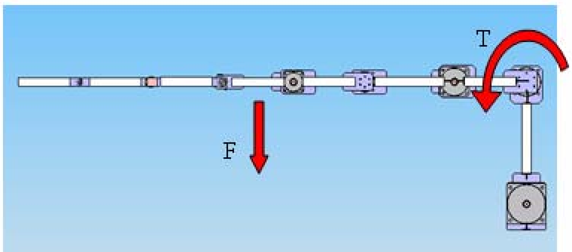

Figure 4: Depiction of large torque-inducing orientation of the second lowest motor

The largest torque constraints, upwards of 2200 Nm, are on the base, bottom-most, motor. At this scale, the only traditional motors available that could achieve this were overly large—two to three feet in diameter. Instead, our design employs harmonic drives which greatly increase the amount of torque that can be supplied with a smaller motor.

Of the eight motors within the design, five have harmonic drives attached to them. A faceplate is attached to the motor's gearbox which itself is attached to the drive with a collar around the shaft extending from the gearbox. The last three motors, most distal from the base, are attached directly by the shaft on the gearboxes. The harmonic drives, while enabling sufficient torque, correspondingly restrict the speed at which the panels can travel. This is not considered a disadvantage for the workstation application, as slower movements match well with the proposed application, and is actually preferable from both safety and control perspectives.

3.1.3 Actuator Integration

After selecting the motor/drive combinations, the attachment of the motors to the panels proved an interesting issue. The attachment requirements were integrated in the panel design. Room was left to fit the motors into the panels so that the gaps between the panels were minimized while retaining the maximum flexibility of movement. The brackets designed to attach the motors to the panels can be seen as blue plates in Figure 3. These plates were also created from 6061 T6 aluminium in order to make the wall system light while retaining as much strength as possible. The torque calculations were performed incorporating the weight of these plates, the additional weight of the motors, four flat panel computer screens, and an additional 10 pounds (4.5 kg) in each panel to accommodate future sensors and peripherals.

3.1.4 Torsion Management

Responding to the potential for the panels to twist around the vertical axis, brackets were created to connect the panels along the sides (Figure 5). These would limit the torque along the z-axis the panels could exert, as well as give more stability to the system. These brackets will be connected through a simple hinge joint.

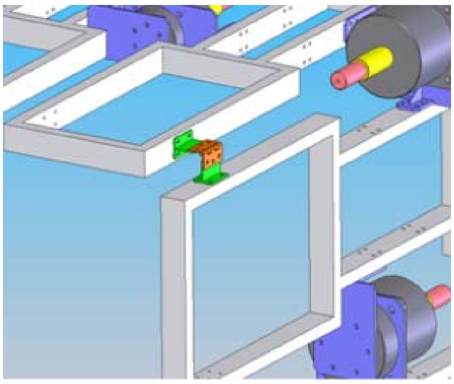

Figure 5: Hinge and smaller bracket design

If this solution does not seem to limit the torsion enough, vertical rails (Figure 6) are envisioned to guide lower panels upwards and downwards, lending stability to the overall system. Such rails may or may not be used in the final design, but having them would ease the torsional load on the system.

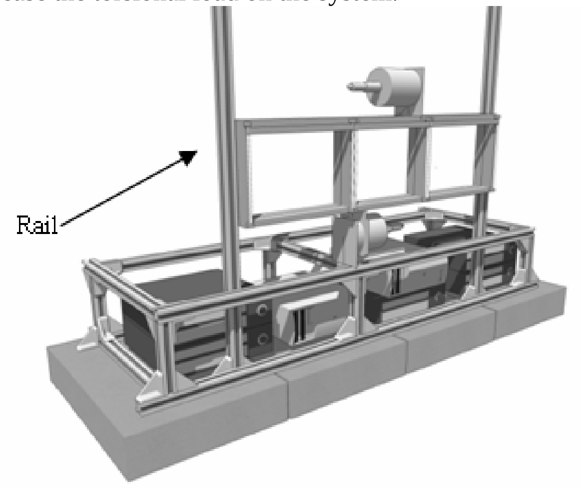

Figure 6: Optional rails limit the torque of the panels

3.1.5 Base Design and Construction

With significant mass being moved within the workstation structure, a solid foundation for the system is essential. After significant design iteration, a concrete base was selected. The final base design (see Figure 6) responded to the weight restrictions of the building structure supporting the workstation, the ergonomics of having someone sit at a desk in front of the AWE workstation, and the space requirements needed for hardware.

Three reinforced concrete slabs were chosen to be used for the base of this system. Each slab had to have dimensions and material properties to support the weight of the robot without compromising the lab floor resistance; the blocks that were ultimately selected give 100 lbs-per-square-foot pressure to the floor. A workstation base (containing all the control electronics) was designed and constructed from Bosch aluminium components. To attach the base to the concrete, holes were drilled in the concrete slabs and screw sleeves were secured in these holes with epoxy. Bolts securing the Bosch aluminium tubing system were threaded into the screw sleeves, securing the framing to the slabs.

To determine the required mass of the concrete base, simple calculations using torque and the center-of-mass were used. The worst-case scenario is shown below in Figure 7.

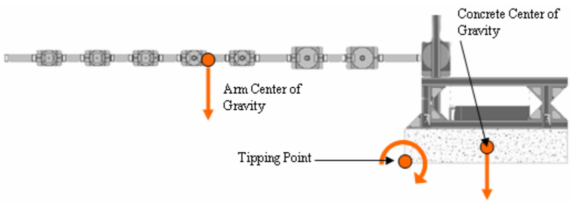

Figure 7: Worst-case scenario for base design

The biggest concern was to make sure the torque created at the center-of-gravity of the concrete base significantly overcame the torque created by the wall when it was positioned in a horizontal fashion.

3.1.6 Workstation Control

Control of the overall system is achieved via independent controllers for each panel, within a custom real-time control environment. Panel angle feedback is obtained from encoders on each of the motors. The control computations are performed in real time using a Pentium PC (specifics here), with I/O achieved via a commercial *ServoToGo* interface board. The input signals are amplified by commercial Techron amplifiers. The overall control structure is shown in Figure 8.

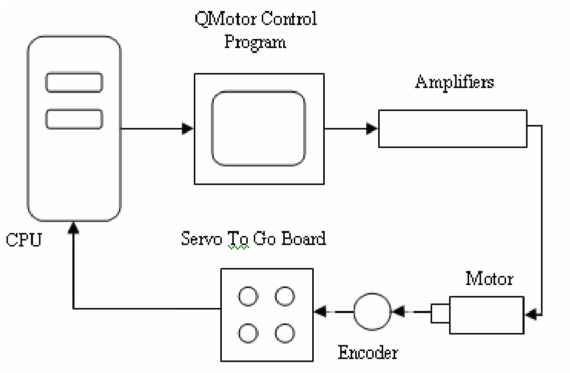

Figure 8: System control structure

A standard PID controller is used for each panel. The position, integral, and derivative gains were tuned for each motor. For the case of the motors with harmonic drives, voltage limit was established and the proportional gain of the controller is set to a large number to ensure that only near the tail end of the movement will the voltage, and therefore speed, taper off. With the relatively slow speeds, tuning of the controller for each of these panels was relatively straightforward and transients are not a major issue. The other three motor controllers need to be further developed as their maximum speeds are significantly higher.

The controllers are implemented on a PC with an Intel Pentium 4 Processor, operating at 2.86Hz, running QNX 3.2.1 real-time operating system. In this environment, QMotor 3.22 allows the user to achieve real-time control response [12],[13]. The control algorithm was written in C++. The system is currently operated in set point mode (moving between fixed pre-set configurations) but we will shortly move to full trajectory control. In the current configuration the user employs the QMotor interface for the input of desired trajectories for the panel and workstation, system monitoring, etc. (Figure 9). The user can also perform tasks such as data logging and online gain tuning was performed using Qmotor. It also allows the user to easily swap between different control modes.

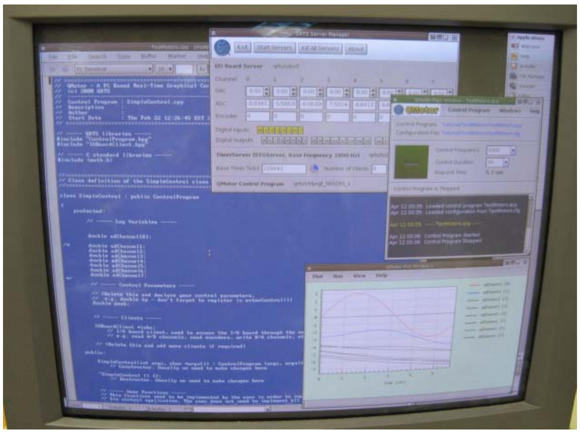

Figure 9: Screen Shot of QMotor and the C++ Skeleton Program (blue screen)

3.1.7 Construction and Testing

The base (Figure 10) was put in using fork lifts because each block weighed approximately three hundred pounds.

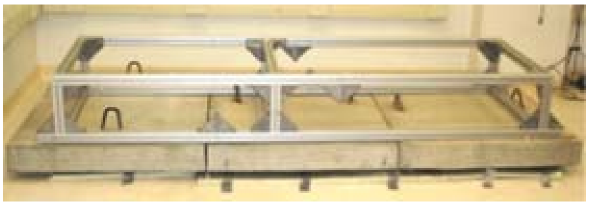

Figure 10: Concrete Base

From this strong foundation, some of the motors and panels were tested. Shown in Figures 11, 12a and 12b is the assembled version of motors 3,4, and 7. Motors are numbered from 0 through 7 from the concrete base up. Each motor can move the panel above it to change the configuration and adapt to the user's needs. Figure 11, below, shows the rest configuration as was depicted in Figure 1.

Figure 11: Front view of AWE flat

Figures 12 a and b show two configurations of the workstation. The experiments to date have been successful. The panels move easily. We expect a smooth transition from this version into the smart panel version. Panels in the future will become "smart panels" when they are outfitted with peripherals in the next several months; these peripherals will range from white boards and lighting to more active elements such as computer screens.

Figures 12 a and b: two possible configurations for AWE

The gains for each motor needed to be set. Table 1 shows the maximum speeds that the motors assemblies allow. The motor assemblies 0 through 4 and 7 are all use the same motor. The different max voltage to each motor is differs because the input torque allowed by the harmonic drive attached to the motors.

Table 1				
Motor assembly number	0	1	2	3
Max voltage to motor (V)	3.87	6.11	6.11	7.13
Max output speed (rpm)	1900	3000	3000	3500

Table 1 continued				
Motor assembly number	4	5	6	7
Max voltage to motor (V)	7.13	36	24	15
Max output speed (rpm)	3500	2650	8380	6270

Table 1: Voltages and speeds for each motor

4 Conclusions and Future Work

This paper describes the design, construction, and initial testing of a novel multi-panel robot system. The design is unique in creating, for the first time in hardware a kinematically redundant robot surface. The reconfigurable workstation application for the system also represents an innovative direction in human-computer interaction in work environments. Taken together, the resulting system provides a unique testbed for conducting innovative research in redundant robotics and human-computer interaction.

In the immediate future the research focus is on completing the hardware and testing. The two lower panels will be equipped with three flat computer displays. The topmost panel will be equipped with lighting elements and audio speakers will be located in two panels. A projector screen attachment will be added to the intermediate panels for presentation purposes (Figure 13a). Panel elements not featuring display screens or other equipment will be covered with Alucobond™, a lightweight plastic-aluminium hybrid material that function as a whiteboard, making the workstation something of a giant, active easel. Iterative usability testing of the resulting system will be performed beginning in Autumn 2007 by the Human Factors Psychologists to evaluate the performance of the AWE workstation. The design will be iteratively modified based on the results of these tests.

(a)

(b)

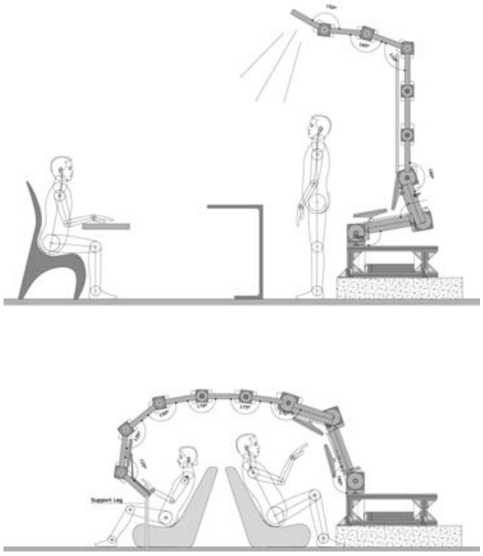

Figure 13: Configured for (a) presenting, and (b) gaming

As a key element of our overall Animated Work Environment (AWE) project, the workstation will, in subsequent research phases, combine with other efforts envisioned by the research team, including a "smart box" (that allows for storage and retrieval of both digital and analogue materials) and a programmable, mobile continuum wall element (oriented horizontally and complimenting the vertical work station described here by defining more precisely the shape of the room). We also intend to explore how multiple workstations, smart boxes, and continuum wall elements combine with programmable lighting and audio as well as select, complimentary IT components designed and developed by the wider IT community to create an intelligent workplace at the scale of a large room or office, greatly amplifying the possibilities for working life in a digital society.

5 Acknowledgements

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