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# Viki Humanoid: Towards an Integrated Approach

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**Abstract**

Our goal is to develop techniques and a work methodology that allow conceiving and building robots, and more in general artefacts, with an integrated approach. This is due to different reasons. First of all, we believe that such an approach is economically advantageous, more efficient, faster, and leads to new design attitudes and "state of mind" with respect to an engineering point of view. In contrast to the top-down approach of equipping a humanoid with as many sensors, motors, power, etc. as possible, we developed a bottom-up approach to the construction of humanoids – an approach that attempts to minimize the robot complexity. For the development of the bottom-up approach we find inspiration from recent work in embodied artificial intelligence that puts emphasis on the correspondence and interrelatedness between material, electronic hardware, energy use, and control. Indeed, the Viki humanoid robots were able to win the world championship though they include much less sensors, motors and energy use than their competitors.

## 1. Introduction

Our goal is to develop techniques and a work methodology that allow conceiving and building robots, and more in general artefacts, with an integrated approach. This is due to different reasons. First of all, we believe that such an approach is economically advantageous, more efficient, faster, and leads to new design attitudes and "state of mind" with respect to an engineering point of view. Here, we will try to describe a working example of such an idea.

As a first step, in contrast to the top-down approach of equipping a humanoid with as many sensors, motors, power, etc. as possible, we developed a bottom-up approach to the construction of humanoids – an approach that attempts to minimize the robot complexity. The approach is shown with the development of the Viki humanoid that won the RoboCup Humanoids Free Style World Championship 2002. For the development of the bottom-up approach we find inspiration from recent work in embodied artificial intelligence that puts emphasis on the correspondence and interrelatedness between material, electronic hardware, energy use, and control. By finding the right balance and relationship between these components of the system, it becomes possible to develop biped walking and other humanoid behaviours with much simpler hardware and control than is traditionally envisioned for humanoids.

The second step to take is to realize a proper user interface to guide/control such robots, as Viki. This interface shall have different level of access, accordingly to user age, cultural background, as well as, user's desired level of intervention. In such a way, we feel to guarantee a wide level of usability and a good flexibility of the object.

The third step is testing the robot produced in a social context, such as schools, industries and etc.

Once all of that is done, one can easily go back to the design level and re-shape the robot/artefact or interface so to fine-tune it to human and/or industrial needing.

In the present article, we describe our attempt to go through the first phase (or step), where we try to keep robot complexity low.

### 1.1 Viki Humanoid

In order to explore the methodology, we developed the humanoid robot Viki. It is our working hypothesis that morphology plays a crucial role in intelligence and intelligent system. Unfortunately, in the past, many researchers have neglected the investigation of the role of morphology. In artificial intelligence robotics, many researchers looked at optimization and adaptation of control on a fixed hardware platform, and therefore optimized to a specific hardware platform only, and not to the overall problem solving behavior. With the Viki humanoid work, we would like to emphasize that optimization towards the best behavior on a global task should happen by finding the right balance between hardware, material, energy use, and software. Indeed, for the first prototype, our software is fairly simple, and becomes a primitive form of a behavior-based system, inspired by the work on behavior-based robotics [1], and our own work on using behavior-based systems for edutainment robotics purposes [2,3]. By purpose, we chose a simple form of control in order to show that it is the right bottom-up mentality in the design process that leads to the result rather than the control in isolation. Indeed, we find that only few motors and inexpensive sensors are necessary, and that a simple control is sufficient, if they are used in a bottom-up approach where all components (hardware, software, mechanics, energy use, control, etc.) are designed for the integration to achieve the overall behavior.


Figure 1. Viki humanoid robots making dancing performance.

## 2. Mechanical Structure of the Robot

The mechanical structure of the robot is based on several simple parallel or non-parallel prismatic structures, which allow us to simplify the mechanical design so that very few actuators are needed for mobility.

In the robot 5 DC 6 Volt motors are applied for the upper body, the hips, the legs rotation, the arms shift. We designed specific plastic-made units (12 units in total) to increase stability of the robot and to allow motors installation (see fig.1). The units were made so that they fit with the standard LEGO sizes, which allowed us to use a number of LEGO units in the final robot's structure where it was possible from durability point of view.

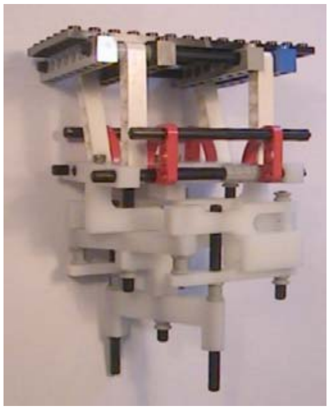
Figure 2. Plastic structure compiled

All the motions of the robot are assumed quasi-static on the design stage but it is possible in the later prototypes apply some dynamic motions using principles, which we introduced in our recent publication [4].

The upper body structure uses one motor for both the main weight shift and legs extraction-contraction. One non-parallel prismatic structure is used. The operation is based on combination of two pulling strings (at the left side and at the right side of the upper body) and legs structures loaded by springs (rubber bandages in the simplest case). Strings actuated by the same motor in a way that while one string is pulled in by a round pulley the other one is released with the same speed from another pulley. The properly adjusted structure works so that the main weight shifts in between two extreme positions. While the main weight is shifting it performs a very small effect on the motion of the legs. But when the extreme position is reached and the main weight is shifted, the leg extraction from one side and contraction from the other side is started (high load phase figure 3).

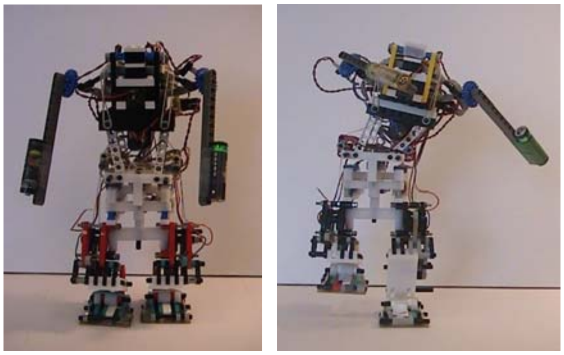
Figure 3. Left: low load phase. Right: high load phase.

The extraction of one leg together with contraction of the other one leads to balancing of the robot on extracted leg. The maximum possible extraction of one leg allows taking the other leg off the ground for about 2-3cm. So, it is possible to perform a step. The step action is performed by hips structure that uses one parallel prismatic structure actuated by one motor in the middle (see fig. 4). So, depending on which leg is on the ground, the left step forward or the right step back (for instance) will be performed by the same hips action.

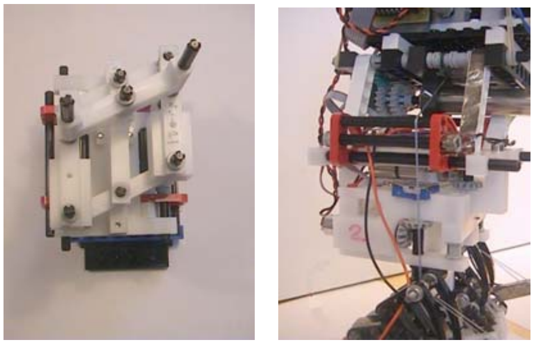

Figure 4. Left: Prismatic structure of the hips.
Right: Actuators of the hips and upper body.

Two motors for rotation of the legs motor are installed in left and right hips units so that it is possible to rotate one leg for more than a half of a revolution. As a result not only the straight step could be done but also steps combined with rotation around the foot place, which turn the robot around the standing leg and also allow the ”swing” leg to prepare for the next action.

One prismatic structure is used in each leg (see fig. 5). The structure is designed so that the orientation of the upper part is always vertical compared to the feet level. It means that it is possible to walk only on a horizontal surface.

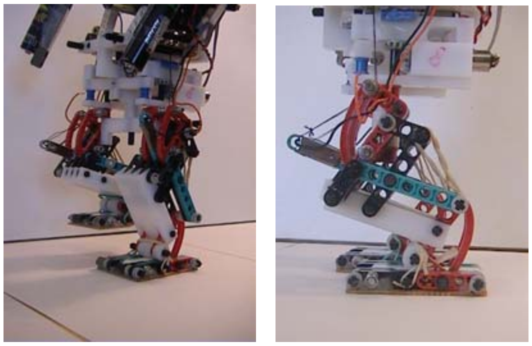

Figure 5. Left: Balancing on extracted leg. Right: Prismatic structure of the legs.

On the figure 5 the structure of the legs actuated by string-spring system can be seen. While the pulley of the upper body pulls up the string, the leg is extracted and the spring is loaded. The rear action (the string unwinding from the pulley) leads to the contraction of the leg actuated by the spring, which was loaded before during extraction phase.

Finally, one single motor is used to shift both arms to the same side.

## 3. Electronic hardware

Viki’s control system is built to be minimalistic in nature, modular and highly reconfigurable. The control system is centered on a rather powerful CPU with the peripherals connected on an I2C bus with a single motor controller being interfaced directly to the CPU as the exception. This allows for quick reconfiguration and can be expanded or shrunk as desired for the particular purpose. Since Viki is controlled by five motors, four motor drivers with local computational power was attached to the bus along with eight analog to digital converters for feedback from the angular sensors. Two 3.6-volt lithium-ion polymer batteries[1] connected in series to offer 7.2 volt power to the entire system.

The CPU in Viki is a AMD186ES micro controller which essentially is an Intel 186 clone wrapped in a micro controller layer that, amongst others, offer two UARTS, timers and several bi-directional I/O pins. The micro controller is supported by 512Kb of working RAM and approximately 0.7Mb of FLASH disk for program storage and file-creation. The system runs an embedded DOS compatible with the IBM DOS allowing for program-development on a PC with any DOS compiler.

The I2C interface to the CPU was implemented in software on top of the DOS and got therefore limited to a bandwidth of 0.1 kHz.

To control the motors used for actuating Viki’s legs, hips and upper body a distributed motor control was implemented outsourcing the workload of maintaining speed and direction of the motors. A PIC16F876 micro controller was programmed to act as an I2C slave that could receive information on and maintain the speed and direction of four motors. If the CPU needs the motor for left leg to rotate counter clockwise, it would send a command to the PIC16F876 that makes the

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[1] Battery prototypes sponsored by Danionics

motor do so. This is a very low cost and flexible solution that allows for any number of "outsourced motor control" to be attached to the bus. For Viki only a single was needed.

Both solutions, the outsourced and the internal, were using the L293D, a full H-bridge motor driver with internal protection diodes, to drive the motors allowing applying ±7.2 volt to the motors.

For feedback on the angular position of hips, the rotation of the legs and the displacements of the arms four commercial linear potentiometers costing 0.70 US$ each was built into Viki at appropriate places to offer a continuous signal for A/D conversion.

Flexing of the legs is done by displacing the upper body thus pulling a string, and extraction is done by rubber bandages. Two extremities sensors (switches) were implemented to detect the end of these motions.

All six feedback values was converted to an eight-bit value using the PCF8591 analog-to-digital converter from Philips interfaced to the CPU via the I2C bus.

The design of the control architecture and the actuation of the body allow Viki to operate for approximately half an hour before a recharge is needed. Minimizing the CPU further to an even more simple architecture as the current one consumes about 2/3 of the total power dissipation may increase this significantly. In contrast to that an even simpler solution with a PIC micro controller would consume only 7% of the total power dissipation.

## 4. The software

We decided to work out some strictly sequential control routines. Therefore, the Behavior-Based Algorithm that we implemented, at a primitive behaviors level, had to control one single motor at the time. Despite of such limitations, results were quite satisfying.

With the sensors, we could measure the arms position (one rotation sensor); the hip position (one rotation sensor); the legs rotation (two rotation sensors, one for each leg); the robot's upper body oscillation (two contact sensors, one for the left and the other for the right side upper body movements).

We also implemented two so-called "virtual" sensors, a time measure we used to let the robot keep on bending the upper body to one side in order to lift up on the two legs. In general, inputs were quite "noisy" and sensors, as usually happen with cheap ones, differed one from the other quite a lot, both in performance and measurements (i.e. in accuracy and fidelity). Also the motors performance did not show accuracy and coherence. This was not due to batteries power consumption dynamics, only. In practice, they all differed in speed and, consequentially, in power.

Due to the high level of turbulence in both the input and the output flow, we needed to elaborate a fairly accurate and robust calibration routine to be run on each robot. Such a process was somehow necessary to control the robots behavior at the best, and it would decide parameters for inputs (i.e. both the real and the virtual ones) and output flow (i.e. motors speed, timing and etc.). Such parameters were then recorded on a log file and downloaded within the robots hard disk to be used with our behavior control algorithm.

### 4.1 The simple algorithm

To control Viki, we decided to develop a behavior-based algorithm. To do so, we first implemented (and carefully tested) a whole set of *primitive* behaviors. Both because of theoretical issues and because of the partial unreliability of the input-output system, we had to shape out such primitive behaviors in a very 'molecular' way. Basically, each single movement or fraction of it was coded.

After the primitive layer was drawn, we started up by building a second layer trying to combine, as many as possible, significant and compatible couple of primitives, the *mates*. Two primitive behaviors do not need to belong to two different input-output systems, but they can also be a proper combination, of the same one. For example, (A) move arms to the center, plus, (B) move arms to the left.

The third layer is the *patterns*. Patterns, assemble together both single primitives and single mates. Also in this case, we applied the same criteria of significance and compatibility used to build the mates. For example, in such robots, a pattern for the upper-body control is built in such a way that balancing the body is at the principal level of priority. Therefore, moving the upper-body from left to the center can be done by: (A) Move upper-body to the left to center, first, and then (B) move arms to the center, plus, (C) move arms to the left. On the contrary, a sequence, or pattern, like (B and C) and (A) would bring the robot in a very unstable state. (This is when robot the body is still on the left side and the arms move to the center, therefore loosing their function of counterweight).

After this second step, a further behavior level, the *movements* one, was realized. A movement can be any possible sequence of *primitive* + *mates* + *patterns*. For example, in the "lift the left leg" routine, one of the most simple and reliable ones we built, we probably had many more routines than one would expect. They were (we here suppose the upper-body is known to be on the left): Move upper-body to the left touch sensor off; Timer Start; Move upper-body T milliseconds. (i.e. to the center); Timer and Motor Stop; Move arms to the center; Move arms to the right extreme; Move upper-body to the right touch sensor on; Timer Start; Move upper-body right for T milliseconds. (i.e. lift the left leg); Timer and Motor Stop.

Once the movements layer was ready we moved on the *actions* level. Again, an action can be any possible sequence of *primitive* + *mates* + *patterns* + *movement*. For example, an action can be the (A) lift the left leg described above, plus, (B) move hip left.

By combining movements (and, of course, their sub-categories) we, finally, reached the *basic behaviors* level. A basic behavior, for example, could be the one just described, plus, a "move the left leg down" mate (i.e. it simply counts time before turning off one motor). The resulting basic behavior is "one step forward left".

By assembling basic behaviors (and their sub-categories) we could then obtain *intermediate behaviors*. For example, "one step forward left" plus "one step forward right" produced a "walk forward" intermediate behavior.

At this point the game is done since we only needed to link intermediate levels (and their sub-categories) into chains of *high-level behaviors* to obtain beautiful, efficient and coordinate acts such as the twelve humanoid robots dance, rewarded as the best free style show in RoboCup 2002. With this control architecture, it is very easy also to design numerous other behaviors.

## 5. Discussion and conclusion

For a future development of Viki, we envision different issues to be touched upon. First of all, we will include a third battery, in order to be able to control all motors simultaneously, ensuring much faster movements. Further, the current Viki humanoid robot is not able to walk on inclined surfaces. Only few biped robots in the world are able to walk on inclined surfaces with small inclinations [5]. We believe that after some years, our next prototype(s) will be able to perform this action as well because simplified leg structure leaves more space and possibilities for implementation of other systems like active balancing-contact force detection for identification of the surface inclinations. Such a system is now under development.

We developed the Viki humanoid in order to show the importance of a bottom-up approach to the design of humanoid robots. In such an approach, one should look at finding the right balance between hardware, software, mechanics, material, and energy use. Our experiments show that we were able to win the RoboCup Humanoids Free Style World Championship 2002 with such an approach, even though / because it resulted in a much more inexpensive design than the competitors, and because it resulted in the focus on achieving the overall behavior by an interplay between the necessary components. In general, we hope that this and other similar experiments/results can open a discussion in the scientific community regarding the importance of morphology in intelligence and intelligent systems.

Further, we are currently developing the user-friendly interface for guiding and programming the Viki humanoid robots, so that most non-experts can develop behaviors for the humanoid robots. This work takes inspiration from our user-guided behavior-based system for soccer playing robots for RoboCup Junior [3]. Once this goal is accomplished, we will go through the third step, in the logic of our Integrated Approach method, and test the whole product on different situations.

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