Development of PetRo: A Modular Robot for Pet-Like Applications

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ABSTRACT

We have designed and are developing a modular robot system called PetRo (Pet Robot) as part of the ReLIVE project. In this paper we briefly introduce the ReLIVE project to give an overall picture of the context within which we are developing PetRo. We compare the design and functions of PetRo to the modular robots we have surveyed, we also give a listing of the Degrees-of-freedoms our configuration deliver. There have been several issues to address during the development of PetRo such as the design of the shape and joints. We present the results we have achieved as well as the simulations we have run to analyse the mobility and self-assembly of the system in a combination of one, two and four modules. More specifically the outcomes from the fabrication of the first module are presented as well as the necessary changes in the design required from the results. Several trade-off had to be made between the complexity of the design and the simplicity of the actuation and control; we present these alongside our reasons to select the current configuration with self-configuration and overall mobility in mind. We also put forwards proposals regarding the inclusion of an array of sensors for an autonomous behaviour, we explain our vision of a herd of PetRos with social behaviours.

Keywords: Modular robots, pet-robot, self-configuration

1. MOTIVATION

As a research and development organisation, one of the main areas we are investigating is novel interactive systems. Our vision for these systems is one of solutions that overlap traditionally separated areas of technology. Indeed all our projects are multidisciplinary ones involving artists, designers, engineers and scientists. Our current focus is the ReLIVE [1] project, an interactive system that delivers to its user a comprehensive and multi-dimensional experience. It is a synergy between interactive devices, virtual environments and robotics. Our aim being to blur the boundaries between the real and the virtual world.

2. THE RELIVE PROJECT

ReLIVE is a three-part research project involving the design of a novel interface device, a communicative and ‘enjoyable’ collaborative virtual environment and a pet robot.

Essentially it is a feasibility study of an Interactive System based around a user, his/her representation in a virtual environment (VE) and a pet robot reacting to both the user’s actions and the events occurring in the VE.

The three components of ReLIVE are:

- **InterCUBE**: A novel interactive device at the user end as a gateway to a collection of functions and applications linked to the two other components of the proposed system. The InterCUBE has been designed to require the simplest possible interaction.
- **Commedia Virtuale**: A Virtual Environment (VE) community, linked to the interactive device and featuring expressive avatars and artefacts. This environment is inspired from Commedia dell’Arte, 16th century Italian improvisational theatre.
- **PetRo**: A pet robot reacting to the user’s instructions and also acting as a projection into the real world of the VE.

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The ReLIVE system will present to the user a continuous interactive experience without discontinuity between the real and the Virtual Environment. We have developed a demonstration prototype for the interactive device. The main idea is to develop a hand held manipulable interface that would closely match the interaction requirement with the VE and the Pet robot, as we understand them. We have also built up expertise in the issue of expressive avatars and communicative VEs, we intend to exploit this expertise and deliver an environment that is both supportive of social communication and linked to the user's location in the real world. The system is also designed to deliver a location dependent set of applications to the user, like tourist information. We are developing a modular pet robot to fulfil several functions: to be the physical embodiments of a pet avatar from our proposed VE, and to be a semi-autonomous pet like an AIBO robot.

PetRo is the projection of ReLIVE into the physical world. Looking at the success of the SONY AIBO pet robot, and the phenomenal adoption of the Tamagochi, we feel confident in the relevance of the pet robot in our design of ReLIVE. Especially that in our case the robot is also linked to the virtual environment.

When designing the robot we had to make sure that it was a successful choice not only by assessing the functions such a design would deliver but also by checking the aesthetic values our design will have. If the robot was to be used as a pet it would have to be sufficiently animal like in it visual appearance.

3. PET ROBOT

We define a pet robot as being a robot capable of pet-like behaviour. A pet is interacted with through emotional involvement and relationship as well as through direct instructions. The robot interaction with its user must be similar to a pet/master relationship. Such an interaction requires mobility, the monitoring of the user's instructions and some autonomous behaviour. The pet robot should use a combination of sensors to choose and recognise its master, his home and power supply ('food'). It should engage into play and be capable of expressing emotions such as joy, sadness, and curiosity. Most of its behaviour should be triggered by events which will change with time, to show maturity and good training. An 'adult' pet will be more skilled but more reserved as well. PetRo design has been chosen to deliver in various combinations different animal-like shapes.

The design needs also to deliver a robot sufficiently articulated to deliver some sort of body expressions postures and movement akin to a pet expressing emotions. Indeed the anatomy of the robot should allow the rendering of numerous body expressions and makes possible various locomotion modalities like walk, run and jump.

4. MODULAR APPROACH

The main advantage of a modular robot is the capability to reconfigure itself and change shape by rearranging the modules. This can be of particular value in rough and not predictable environments condition. Highly articulated robot with more degrees of freedom (DOFs) than traditional robots can be used for demanding tasks and in difficult conditions.

We see modular robot as reconfigurable systems made of a single module that repeat itself to compose different structures. In our approach we have designed our modules to be capable of autonomous motion independently of the remaining modules. Thus our modules could be scattered in the field of operation and be capable of self-assembling into a modular robot. This is a very important difference with most of the current modular robots being developed. The inconvenient of autonomous and detachable modules is the need to include in each module actuators, sensors, power supplies and control units. In fact each module could be looked at as a robot on its own. Another drawback is the actual size of the module. The current prototype fits in a 35cms cube.

PetRo was designed as a modular system capable of self-assembling into a variety of shapes. While two modules will make up a dog-like pet robot the assembly of more modules deliver other animals configuration.

1. Other modular robots

At XEROX-PARC a series of modular robot has been developed, Polypod is a modular robot based on two modules repeated in alternation many times. The next generation of robot is PolyBot, which is based on a single module with a single DOF [2].

CMU I-Cubes is a modular robot based on two sorts of modules, active linking modules (called links) and passive connection elements (called cubes). All the modules let power and data flow to their neighbouring modules [3]. Another design principle was used at the Dartmouth College with the molecule. A Molecule module consists of two atoms linked by a rigid connection called a bond [4]. Each atom has five inter-Molecule connection points and two degrees of freedom The molecule robot is a small-scale bi-module system. Each male or active molecule capable of aggregating with passive or female molecules.

At The University of South California, the CONRO system has been developed as a miniature reconfigurable robot made from identical modules. The base topology is a snake where modules are connected in series; the system can configure itself to possess legs. Each module consists of a CPU, memory, battery, motors and sensors [5].

Most of the modular robots developed rely on connections having already been established between the modules, as a result the configuration algorithms are based on the modules using each other as stepping stones. The scattering of the modules and their regrouping is therefore not possible. Another drawback is the limited mobility resulting from this approach. However, each module can be very simple from a mechanical and electronics point of view requiring few actuators and sensors.

2. PetRo single module

The design of the single modules had to fulfil several requirements. Namely, to be functional even as a single isolated module, and having potential to include many functions. We have produced a highly mobile omni-directional design, as such a single module is always standing up and does not have an specific predefined direction of displacement. The design delivers also good connectivity with other modules through four connection points. In essence a single module could be described as a set of legs linked by a core element.

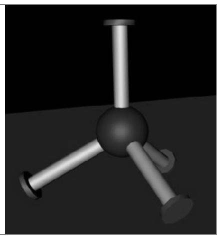

Fig 1: PetRo Single module

PetRo is a 'quadripod' with no prominent direction nor orientation. All the legs of the module are at 120° from each other.

3. PetRo joints and Degrees of Freedom

The joints and the number of degrees of Freedom (DOF) were designed to allow the modules, either single or in combination, two modes of locomotion. At the end of each leg is a 1DOF joint with a rotating wheel. Allowing the single module to have some limited mobility, and for fast walking motion. The legs are attached to the core through a 2DOFs joint; this is to enable the walking-like motion of the combined modules. The Rotation of the arm is also essential to the connection of two modules to one another, as explained in the next section.

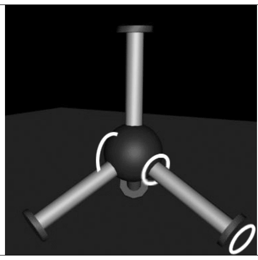

Fig 2: 3 DOF per leg (perspective)

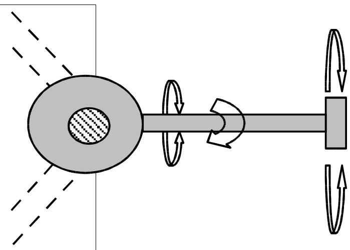

Fig 3: Plan view of one leg

As a single module, the wheels at the end of the legs would allow the module to move at a limited speed and agility in a series of circular paths (as shown in figures 4.1 to 4.4). However in combination of two or more modules, the robot will be capable to move using a walking motion. Such a motion is essential in rough terrain and to deliver a robot acceptable as a pet. Each leg has therefore 3 DOFs, Combining the whole set of leg results in each module having 14 DOFs

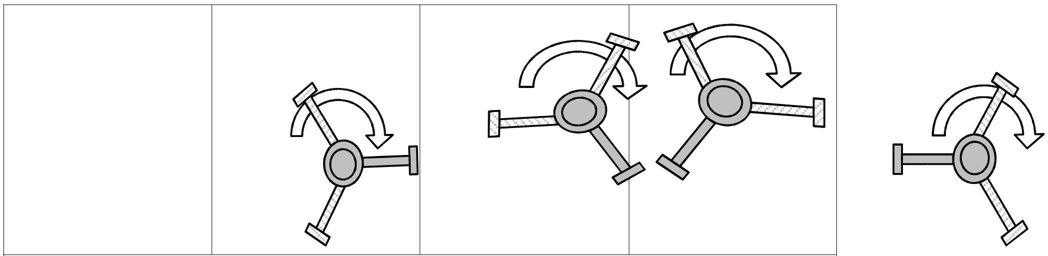

Fig 4: One module displacement based on a series of rotations.

4. PetRo as a 2 modules assembly (dog)

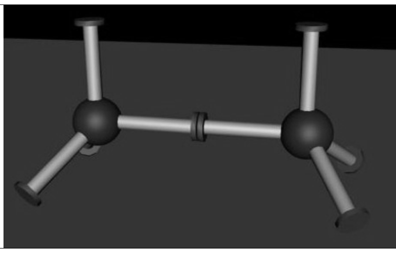

Fig 5: Two modules combination (dog)

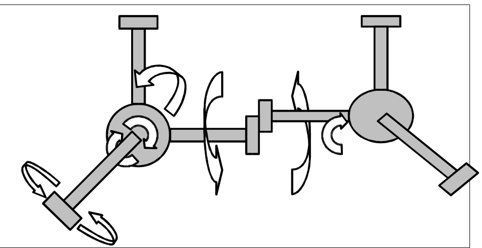

Fig 6: The combined DOFs of the 'dog'

This is the most important configuration as it delivers a dog-like robot most likely to be perceived as a pet robot. In this combination two modules are connected through one of the legs, which acts as the body of the pet. As the legs connecting the two modules can change the angle relative to the core of their respective module, this provides some flexibility for the assembly. Two modes of locomotion are possible, a four-wheel displacement and a walking motion.

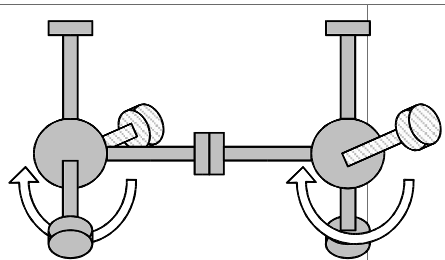

Fig 7.1: Walking motion for the 'dog' configuration

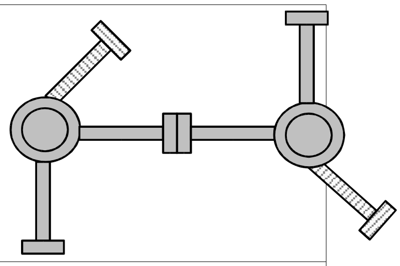

Fig 7.2: Plan View

In the walking motion two diagonally opposed legs are lifted and rotated together like a quadruped animal. The dog assembly can also run, this happens when the walking locomotion is enhanced with a spinning of the wheel, creating a much faster displacement.

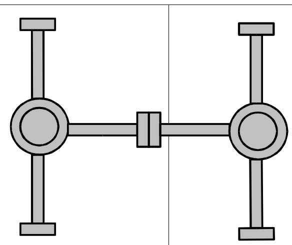

Fig 8.1: 2nd Walking mode Plan view of step 1

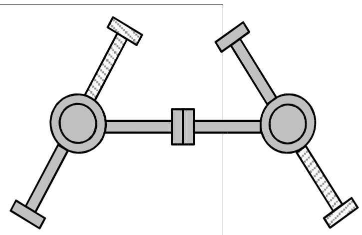

Fig 8.2: Plan view of step 2

Another walking mode is possible as shown in figures 7.1 and 7.2, it is similar to lizard locomotion. In this mode the wheels of the active legs spin to actuate the movement. This displacement mode is possible thanks to the joint at the base of the legs linking the two modules. These are equivalent to the shoulder and waist joints found in lizards.

5. PetRo as a 4 modules assembly

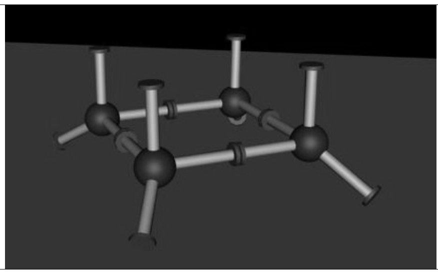

Fig 9: 4 modules combination (spider)

The principal interest of this configuration is the increased stability of the robot. In this combination, both four-legged walk and four-wheel drive are possible. The flexibility of the structure is a result of the connection between the modules as each leg is attached to its module core through a 2 DOF joint.

Were are looking at further combinations of modules. However flexibility, mobility and more functionality are a requirement for the creation of further combinations.

5. SELF-ASSEMBLING ALGORITHMS

The PetRo module design has resulted in a series of a simple assembling algorithm. It follows these steps:-

(a) Detection of other modules or combination of modules.
(b) Assessment of combination, to check for the type of configuration and the connecting points still available.
(c) Assessment of relative position and orientation of each of the modules.
(d) Meeting point where the modules will connect to make up a new configuration. At this stage one of the module adopts an active role, and the other one is in a passive mode.
(e) Coarse alignment.
(f) Flexion.
(g) Fine alignment.
(h) Connection.
(i) Assembly.

Figures 9.1 to 9.5 illustrate how such algorithm will work for a two modules pairing into a 'dog' configuration.

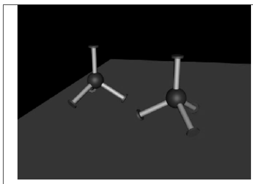	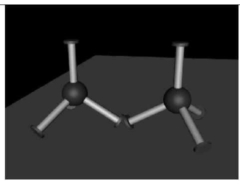	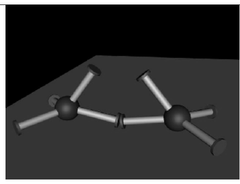	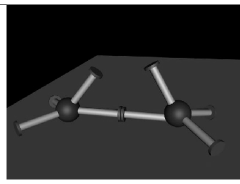	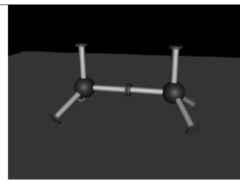
Fig 10.1: Meeting Point	Fig 10.2: Coarse alignment	Fig 10.3: Flexion & fine alignment	Fig 10.4: Connection	Fig 10.5: Assembly

The relative simplicity of the assembly algorithm is a direct result of the mobility of the modules. Such mobility however implies the possibility and the expectation that the PetRo modules will disperse in the environment. The relative location of each module is therefore of paramount importance if they are to assemble into various configurations. The fine alignment of the modules and their connection is the most challenging part of the assembly process, as it is not possible to predict what exact relative angle and position the two connecting wheels will have.

6. SENSOR SYSTEM

To apply the assembly algorithm a series of sensors are required on each modules. Area sensors, alignment sensors, and connection sensors make up PetRo sensory system. Three level of inter-module detection/localisation are necessary, a wide range system for the detection of modules, a coarse localisation link for the alignment of the modules and a fine alignment system. For the first step of the algorithm, i.e. detection of other modules, radio link system has been selected, to monitor for the possible presence of other modules and to set up wireless connections. For the coarse alignment of the modules, we propose an array of IR sensors localised at the core of the module. As for the Connection sensors we have selected an IR proximity sensors with a narrow angle in a similar fashion to [6].
There are other parameters the robot needs to be aware of while operating; these are related to environment awareness and situation assessment.

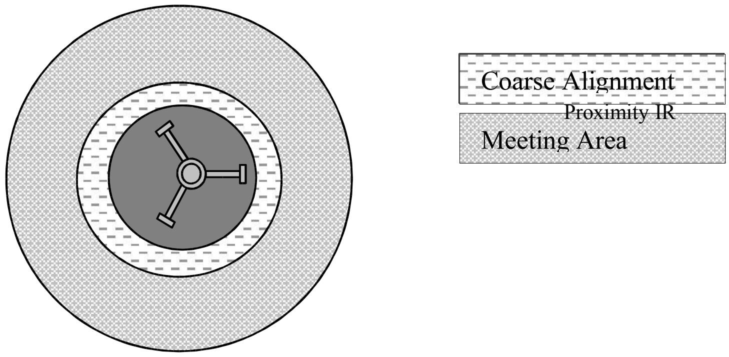	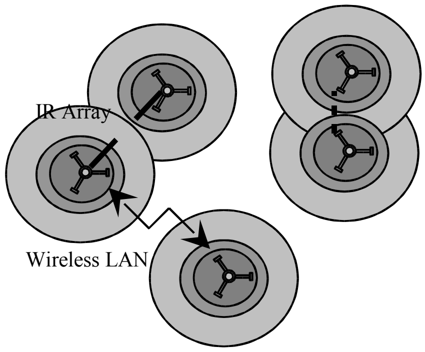
Fig 11.1: Three Levels of Resolution	Fig 11.2: Group communication and detection

As a single module, location, orientation and displacement are also parameters to track. For the orientation we have developed a simple array of tilt sensors for the detection of the orientation of the module. It is based on tilt switches distributed inside the core of the module. This combination has been successfully tested and is used in the InterCUBE device. For the other parameters we have not yet decided which solution to choose, although vision and radio tracking are possible candidates. For example as a pet robot, we plan to use a system of sensors associated with the perception of the user instructions and actions. The embodiment of avatars will necessitate a data link between the InterCUBE as the gateway to the virtual environment and, PetRo.

7. GROUP BEHAVIOURS

As a group of independent systems PetRo robots are conceived to possess various set of behaviour: Assembling into various configurations, collaborating on a mission, and acting as pets. When assembling the module communication is limited to relative location, the selection of passive or active role, and the reliance on the proximity and alignment sensors to achieve connection. The collaboration between units will rely on a wireless LAN where the individual modules and combination of modules a connected and disconnected depending on their location and displacement, this has been demonstrated as feasible [7]. The communication between the robots when acting as pets can be achieved in two ways either directly or via the virtual environment. Fabrication restriction (i.e. space available inside the modules) will determine how much communication is performed between the modules.

Few principles are guiding our approach to group behaviour. The assembly of the modules is essentially about detecting mating partners and applying the self-assembling algorithm, the relative positions of the modules is the most relevant data to exchange. The collaborating behaviour is relying on the distribution amongst the units of specific tasks thus the need for communication.

Two types of scenarios are possible situations one is PetRo walking with his master, and the second is a group of PetRos sent on a mission when they autonomously disperse and move throughout a region.

8. FABRICATION OF THE FIRST PROTOTYPE

We are fabricating the first prototype of PetRo at 1.5 scale of the intended final size. The materials selected are plastic for the legs and aluminium for the core and the leg endings. The electronic components of the robot are distributed amongst the core element and the legs. The legs housing the components actuating their displacement as well as the connecting sensors while the core element houses all the remaining functions. The current challenge we are facing is the design of sufficiently compact joints linking the legs to the core of the module, while housing in the legs all the circuitry necessary to control and actuate their movement.

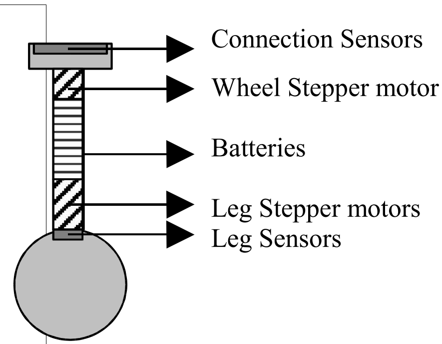

Fig 12: Leg components distribution

Too keep the module design as simple as possible while at the same time delivering the required mobility; several trade-offs have been made. A single module can only have a limited mobility, as it rests on three wheels in a triangular arrangement. For linear displacement, the robot has to perform half-rotations, rather than a more straightforward motion (as shown in figure 4). The distribution of the functions between the legs and the core is also a difficult issue as is the overall weight distribution.

9. CONCLUSION

A novel design for a modular robot has been proposed and a working prototype is currently being developed to demonstrate the validity of the design. Although fabrication difficulties have delayed the delivery of the first prototype beyond the publication date of this paper, we are confident about the validity of our architecture especially that it delivers robustness and mobility. Initial simulations and model used have highlighted the suitability of the design we have selected. Furthermore, we were also able to identify many useful improvements now included in the prototype being fabricated. The novel design of PetRo was successful in delivering a modular robot for pet-like applications. We found that two key parameters are required for a pet/master relationship to occur. The locomotion of the assembled module should be similar to the movements generated by a pet and, the flexibility of the configuration should be sufficient to render a variety of body expressions. Initial set of postures and movements necessary for a pet-like behaviour will render dialogue with the user and emotions.

After completion of the prototype we are planning to shrink the module in size and undergo the fabrication of four modules to explore the 'dog' and 'spider' configurations. The first stage of PetRo development is focusing on testing the design, investigating actuators for the robots, and integrating sensors and control circuitry.

Another avenue to explore is the development of specialised modules with a tool at the end of some of the legs. These modules would have a limited mobility and connectivity compensated by their functionality.

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