The Development of Khepera

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Abstract. This short paper explains how the Khepera robot was developed, from the initial idea to the its commercialisation by K-Team. The goal of this paper is not a scientific analysis but an historical overview of the steps made in the development of this robot since 1991. The papers introduces first the situation of the team who started the development, then decisions made in creating the actual Khepera are briefly described, as well as some important steps in the commercialisation of the robot. We conclude with the current status of Khepera, and introduce other products that have evolved from Khepera.

1 Starting conditions

Khepera was born at the Microcomputing Laboratory (LAMI) of the Swiss Federal Institute of Technology of Lausanne (EPFL) in 1991. Observing the evolution of robotics technology and the developments of other universities, Prof. Jean-Daniel Nicoud, head of the laboratory, decided to start development of a mobile robot occupying less than one cubic inch of volume. The Squirt robot [1] developed in the same period at MIT and the well known Swiss know-how in miniature mechanics and watches probably played an important role in this decision. The development started as a student project by Kaspar Suter [2] and finished in December 1991 with the first prototype. This robot was equipped with a 68HC11 processor, two asymmetric wheels controlled by DC motors with integrated reduction gears, watch batteries, and infrared sensors like the Khepera of today. An obstacle avoidance behaviour was demonstrated at the end of the student project.

During the same period, Francesco Mondada and Edo Franzi were also working at LAMI in the framework of a research project on Artificial Intelligence and robotics, supported by the Swiss National Research Foundation (project PNR23). LAMI was involved in this national project as experts in the field of Artificial Neural Networks (ANNs). After an initial implementation of Artificial Neural Networks on robotic arms by Laurent Tettoni, Mondada and Franzi were convinced that the field of mobile robotics was a good one for testing neural networks. A quick research of existing experimentation tools showed that the only robots available on the market were expensive and difficult to use. The requirements for a mobile robot tool necessary for the ANN project were very different than the specifications of existing robots. As LAMI had all the competences required to build this type of robot, it was decided to link the PNR23 research project with the miniature mobile robot developed by Kaspar Suter.

Hence the desired characteristics of the robot:

- Physically compact, with motors, sensors, batteries and processor all included.
- Onboard computation capability able to support complex algorithms like ANNs.
- Easy to use in basic experiments not only by engineers but also by biologists col-

laborating with the LAMI group. This was a real problem with existing robots at this period, most of them programmed in very strange languages and therefore not accessible to non-specialists.

- Modular, allowing extensions for use in new experimental fields of research.
- Permits investigation into collective robotics.
- Includes a lot of new technology.

The goal of the development was to build around 10 robots for use at LAMI. The team working on this project was composed of:

- Edo Franzi: responsible for all electronics design and low level software.
- André Guignard: responsible for mechanics, electronics layout and prototyping.
- Francesco Mondada: responsible for the development of tools to implement ANNs on the robot.

2 Creation of the first prototype

A preliminary design and prototype was completed in 1992 based on the above characteristics. This first robot (see figure 1) was used for research activity and for demonstrations at several conferences and workshops.

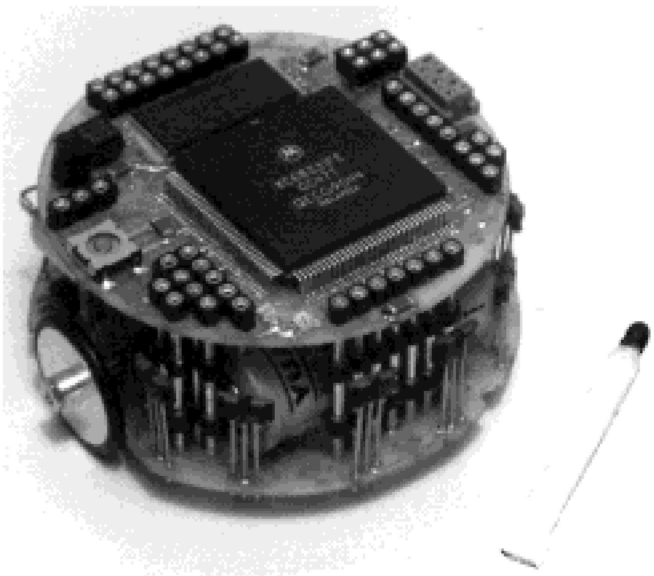

Figure 1. The first Khepera robot built at LAMI. This version had an unusual wheel fixation and no battery recharger connector between the two front sensors. The connection with a recharger was made using contacts placed under the robot.

Some additional interesting features emerged from the use of the first prototypes:

- The robot can be connected to the computer with a wire without disturbing operation (see figure 2). This enable control of the robot from a host computer.
- Being small, a robot has much better relative mechanical resistance. This physical property can be understood by considering a large robot with a diameter of 1 m running into a wall at a speed of 1 m/s and a small robot with a diameter of 1 cm running into a wall at a speed of 1 cm/s. The first case results in catastrophe, the second not.

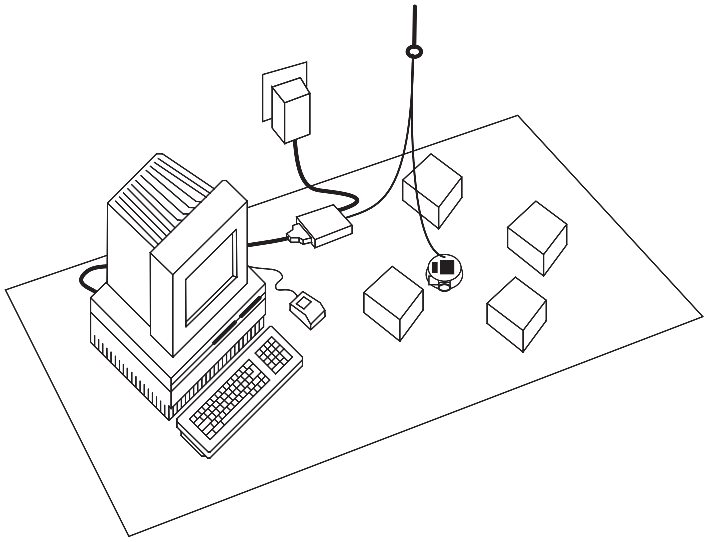

Figure 2. This figure, representing the robot in its desktop environment, appears in many papers and manuals because it shows the main feature of the Khepera robot: the fact that it can be used on a table near a computer connected with a cable.

2.1 Technical hardware choices

In 1992, the new generation of Motorola microcontrollers and in particular the MC68331 provided a new and better solution for building powerful miniature systems. The CPU board of the current Khepera has been built around this microcontroller and is a complete 32bit machine including a 16MHz microcontroller, system and user memory, analogue inputs, extension busses and a serial link allowing a connection to different host machines (terminals, visualisation software tools, etc.).

The microcontroller includes all the features needed to easily interface extensions: memory interfaces, I/O ports and external interrupts. Moreover, the large number of timers and their ability to work in association with the I/O ports are a great advantage.

Due to the size of the connectors and the space needed for the components, a second board was devoted to the sensory/motor functionality. This second board includes two DC motors coupled with magnetic incremental sensors, eight analogue infra-red (IR) proximity sensors and the on-board power supply. The magnetic incremental sensors were chosen for their low power consumption and facility of use. Placing these sensors before the reduction gear yields an encoder resolution of 600 pulses per wheel revolution. The eight analogue IR proximity sensors were also very compact in comparison to other distance sensors. A dedicated electronic interface was built with multiplexers, sample/hold and operational amplifiers. This permits the measurement of the absolute ambient IR light, and by reflection of the emitted IR light, an estimation of the relative position of an object from the robot.

One of the most interesting features of Khepera is the possibility of connecting extension modules on two different busses. One parallel bus is available to connect simple experimentation turrets. An alternative and more sophisticated interface scheme implements a small local communication network; this allows the connection of intelligent turrets (equipped with a local microcontroller) and the migration of conventional or neural pre-processing software layers closer to the sensors and actuators. This communication network uses a star topology; the main microcontroller of the robot acts as a master (at the centre of the star). All the intelligent turrets are considered as slaves (on the periphery of the star) and use the communication network only when requested by the master. This topology makes it possible to implement distributed biological controls. Examples are arm movement coordination or feature extraction in vision, as observed in a large number of insects.

The multi-microcontroller approach allows the main microcontroller of Khepera to execute only high level algorithms; therefore attaining a simpler programming paradigm.

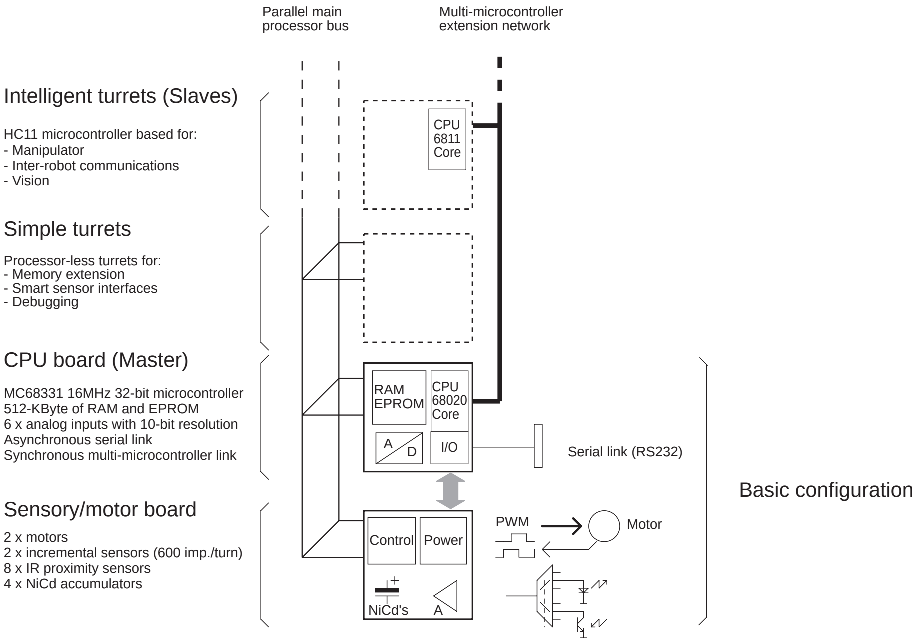

Figure 3. The structure of the Khepera robot: a basic configuration and an extensible structure.

2.2 Low level software support

Managing all the Khepera resources was not a simple task. Controlling the large number of asynchronous events, and the necessity of sharing some critical interfaces led to the development of a complete low-level software system organised as a collection of basic I/O primitives.

In addition, the multi-microcontroller approach and the management of complex tasks required a hierarchical approach to the software structure. This concept shows real efficiency improvements when distributed computation and intelligent turrets (equipped with a microcontroller) are used.

Two software structures are implemented: a single high-level application program and a number of stand-alone local processes.

Stand-alone local processes (e.g., for IR sensor sequencing, motion control, wheel incremental-sensor counting, etc.) are executed cyclically according to their own event timer and possibly in association with external interruptions.

The high-level application software runs the control algorithm and communicates with the stand-alone local processes via a mail-box mechanism.

The decoupling of low and high-level tasks facilitates the development of complex applications.

2.3 Visualisation and programming tools

An innovative aspect of Khepera was its size and the consequent possibility to use it on a table near to the host computer, connected via a cable. This configuration was not very common in 1992. This pushed us, in addition to the development of cross-compilers, to start using software controlling Khepera from the host computer. In this case, the application software run on the host computer and calls the basic primitives of the robot BIOS through a generic high level protocol. All standard and specialised visualisation tools that can control the RS232 of the computer can therefore also be employed to design and debug the control algorithm.

The first environment tested and used by some biologists was LabVIEW, from National Instruments [3]. This software was chosen because it was available at LAMI and was used by several colleagues. Internally at LAMI another software tool was used to control Khepera: Grapher, part of the PACKLIB environment [4][3]

Recently, interfaces have been developed for many other tools, including MATLAB, Mathematica and SysQuake.

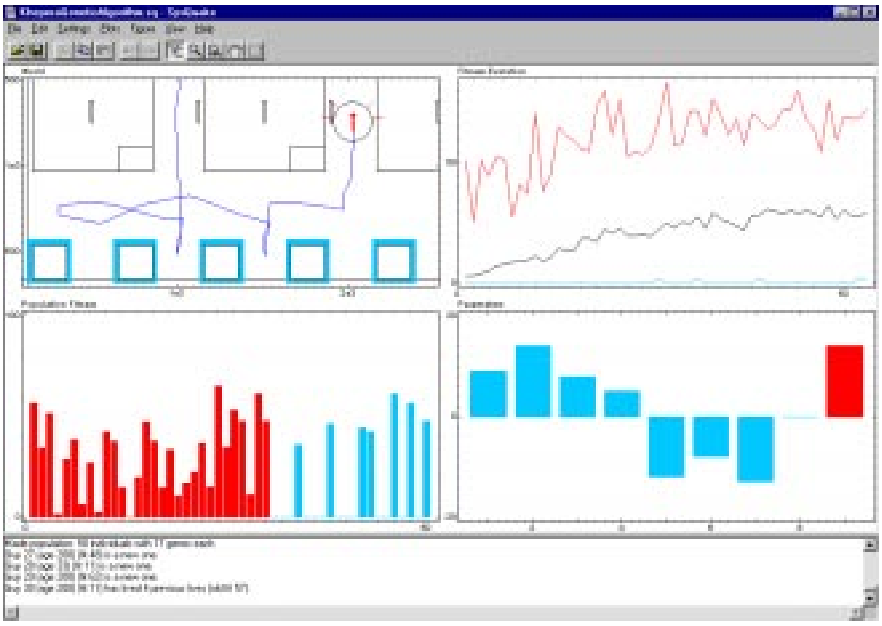

Figure 4. An interactive plot of SysQuake showing the trajectory of a Khepera robot under evolution and some parameters of individuals and population.

2.4 The “Khepera” name

In the beginning, the robot became affectionately known as “cafard” by the people of the lab, which is French for “cockroach”. Although appropriate, this name was lacking somewhat in elegance and Prof. Nicoud, looking for a better name, found “Khepera”, the name of an Egyptian god having the head of a cockroach. A fine compromise between popular opinion and marketing savvy!

3 From the LAMI lab to the K-Team company

3.1 First users

The very first users have been Paul Verschure and Claude Touzet. Neither is an engineer, but were involved in research on neural networks and provided the first feedback from external users. This feedback has been essential in refining the design of Khepera software tools.

With Paul Verschure we tested the first version of the cross-compiler, recompiling some programs implementing the DAC neural network structure [5]. These initial tests, made with cross-compiled code downloaded into Khepera, demonstrated the need of other development and visualisation tools.

With Claude Touzet, biologist, we tested the LabVIEW environment, which offered far greater simplicity in programming and efficiency in visualisation [6]. Claude Touzet wrote the first Khepera user manual around this same period.

3.2 Commercialisation

As mentioned above, the main goal of the project was the production of 10 robots for use in LAMI. In demonstrating the robot, we saw a real interest for this tool and decided to build 20 robots, permitting other universities to use them as well. We finally found an industrial partner ready to build 50 robots with the risk of selling only 10 of them. Several contacts made in 1993 at several conferences spread the interest for this small tool. Similar contacts provided a reseller network, particularly in Japan. Between 1993 and 1995 about 150 Khepera robots were sold and the existing structure of the partnership was insufficient to meet the growing demand. The company K-Team was founded in June 1995 to properly support this commercial activity and has sold, between 1995 and 1999, about 700 Khepera robots, most of them in Japan and Europe.

4 Status and future developments

The Khepera robot has been extended with a large number of turrets, some developed by K-Team, others by LAMI and several universities around the world. New robots have been developed under the same philosophy as Khepera. In particular the Koala robot [7] has a very similar structure to Khepera but on a larger scale.

Figure 5. The new Koala robot has a structure very similar and compatible to Khepera but a much bigger scale.

The new Kameleon board follows the same guidelines, and was developed by the same team as the Khepera and the Koala. Offering compatibility with Khepera and Koala, this board is able to control a wide range of mechanical structures, from student competition robots [8](see figure 6 left) to legged robots for advanced research (see figure 6 right). New directions of development of the "K" family of hardware include the integration of highly interactive software tools like SysQuake [9] and other new robots, keeping always the ambition to provide the best robotic tools for researchers and professors.

Figure 6. A student robot built around the Kameleon board (left) and a legged robot with 8 degrees of freedom controlled by two Kameleon boards in multiprocessor mode (right).

Acknowledgements. The authors would like to thank Jean-Daniel Nicoud for creating the context of this work and Jelena Godjevac, Paul Verschure, Claude Touzet, Philippe Gaussier, Stéphane Zrehen, Dario Floreano, Yves Cheneval and Laurent Tettoni for early testing of their algorithms and of the development tools on Khepera. This work has been partially supported by the Swiss National Research Foundation (project PNR23).

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