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Self-Organised Societies of Connectionist Intelligent Agents capable of Learning
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NEW PROJECT OBJECTIVES

INTRODUCTION

Project SOCIAL aims to exploit/investigate **methods for engineering emergent collective behaviour in large societies of actual miniature agents that can learn and evolve.** The project will ***design and develop SOCIAL[1], a new kind of tangible CAA*** (Collaborative Autonomous Agents).

Although such multiagent systems could be used on a variety of applications (exploration, monitoring), SOCIAL will be utilized to expand the action-horizon of humans in inaccessible fluidic environments found in critical components of material/industrial systems (oil drilling, geothermal plants etc).

Successful collective performance in these missions critically depends upon: (i) accurate environmental perception, (ii) a real time decision making and action loop, (iii) emergent goal directed social behaviour.

In order to meet these requirements, we:

(a) Propose *a novel agent architectural design* based on modular Spiking Neural Network, which will serve as a "blueprint" for agent manufacture

(b) Research direct/indirect *communication* mechanisms for collaborative societies formation, and agent to environment communication.

(c) Design and develop an accompanying *Development Environment,* which will facilitate the evolution of complex agent SNN architectures-multiagent societies, and the development of successive CAA generations.

We aim to prove the feasibility of this approach by:

- Rapid prototyping of hybrid agents acting in simulated worlds using the Development Environment.
- *Building prototypes of* (societies of embodied situated) CAA, capable of *co-operative exploration, fault localization and possible repair missions*.
- Testing these prototypes (initially) in simulated and (finally) in demonstrators of the actual industrial fluidic environments.

OBJECTIVES

The concrete objectives of the project are to:

1. **Design** and **implement a generic modular agent architecture** that can be mapped to the physical design of the tangible agents , consisting of
    - Sensors for perception and navigation.
    - Actuators for signalling navigation and possible repairing.
    - A communication module. Appropriate direct/indirect communication strategies for agent to development environment and inter-agent communication will be researched and implemented accordingly.
    - A computational subsystem implemented with Spiking Neural Networks.

[1] SOCIAL = Self Organising societies of Connectionist Intelligent Agents capable of Learning

- The required glue software to allow interfacing between different components of the agent architecture.

2. **Design and implement a Development Environment** that will allow rapid prototyping and evaluation of successive generations of agents (within each CAA brand). The development environment will include modules for specification, compilation, simulation and evaluation of each CAA generation:

    - CAA Builder, which sets the specifications for the CAA architecture based on a formal model and appropriate library components (e.g. sensors, actuators).
    - CAA Compiler, which takes the specification from the CAA Builder and produces agent SNN description in synthesizable VHDL, or in intermediate language representations which can be executed in Simulator's Virtual Engine.
    - Simulator, which tests the CAA societies according to certain criteria in scenarios implemented within the Simulator as well as monitor the tangible CAAs in the real fluidic environment.
    - Evaluator, which evaluates each CAA generation's performance based on the Simulator and produces successive CAA generations, using evolution mechanisms.

3. **Design a life cycle model for CAA development and a methodology to realize it.** The life cycle model aims at the definition of the work to be performed and focuses on important features of this work. It consists of four stages: specification→ implementation, integration→ simulation→ evaluation, evolution. At the specification stage, a formal model is proposed capable to describe all the necessary parts of the CAA and especially to express the features of temporal neurons. The methodology will be applied to the life cycle model for CAA development and will address, among others, design choices for the realization of the life cycle as well as at quality aspects of the CAAs to be produced.

4. **Develop hybrid agents** which will consist of the aforementioned spiking neural networks ported in FPGA hardware and the necessary software to interface with the simulated environment. Various SNN models will be defined using the formal model and evaluated both in SW and hardware. Ideally both implementations must be interchangeable.

5. **Develop tangible hardware agents and a roadmap to their miniaturisation.** Tangible agents consisting of critical core components (computational/communication subsystem, power supply, subset of sensors) and existing state of the art navigational system for fluidic environments for monitoring, fault localization and potential repair of faults will be produced. Core components dimension will range from 25mm at end of the second year and in the third year this will be miniaturized as far as possible within the range of 10-18mm. The form factor that the core cube can be reduced down to will ultimately depend upon the smallest package size of a suitable FPGA that becomes available during year 2. Focus will be on packaging and interconnections of various hardware modules as well as power management issues.

    Even though the size of individual components are of critical importance for the eventual size of the agent, SOCIAL will also focus on miniaturization techniques which are deemed to have far reaching implications for future information system technologies. A roadmap document considering the feasibility of building micro-nano CAAs in the future, based on the functional requirements set by the larger tangible agents, experimental and theoretical analysis of the technological trends, will be produced.

6. **Implement a proof-of-concept system** using bypass test tubing, a tube filled with fluid (tap water) at quasi static conditions, to replicate aspects of fluidic systems in the priority application, in order to investigate in-situ behaviour of the tangible agents**.** The system will also support the remote monitoring of agents and will be implemented in two levels. Initially, it will consist of **hybrid agent societies,** exploring industrial fluidic environments in simulations. The hybrid agents will consist of spiking neural networks in hardware/software and the necessary "glue" to interface with the simulated environment. Finally, it will contain the **tangible agents** navigating an actual fluidic environment for monitoring, fault localization and potentially repair of fault by CAA societies. Location of the tangible agents in the actual environment will be directly communicated to the development environment for location monitoring purposes.

METHODOLOGY

SOCIAL adopts a problem oriented approach in order to demonstrate the feasibility/validity of the underlying concepts. The proposed methodology aims to provide a concrete framework for developing Collaborative Multi Agent Societies from definition of agents based on appropriate formal models to evolution-evaluation and actual FPGA based hardware implementation.

CAA Engineering Approach

In brief, the engineering methodology is based on the synthesis and analysis of coherent collective behaviour emerging from individual interactions. This is originated by the engineering methodology originally proposed by (Brooks, R. A. Intelligence without representation. *Artificial Intelligence*, 47:139–159, 1991) who decomposes the system into parts, builds the parts and then interfaces them into a complete system. The decomposition is not by function but by activity and the advantage of this approach is that it gives an incremental path from very simple systems to complex autonomous intelligent systems. At each step of the way it is only necessary to build one small piece, and interface it to an existing, working, complete intelligence.

Indeed, in the SOCIAL project, a CAA is a component-based system built around the computational and communication components. In this project, the computational component will be implemented using modular Spiking neural networks which are further decomposed:

- In SNN modules implementing basic behaviours (gradient following, avoid obstacles etc)
- In control SNN module, controlling the expression and combination of the simple behaviours (see Deliverable D5, CAA Architecture).

Development Methodology

The CAA life-cycle model consists of four stages:

<u>Stage 1:</u> Specification

A formal model capable of describing the topology and execution of SNN (computational component) as well as the sensor/actuator components has already been proposed and used.

Based on the formal model, a designer specifies (by using the CAA Builder) all the necessary parts of the CAA.

Stage 2: Implementation – Integration

The specifications are compiled by the CAA Compiler and both XML descriptive code and VHDL code are produced. The VHDL code is used for the implementation of the CAA h/w.

Stage 3: Simulation

The XML code will be used by the Simulator in order to produce executable s/w CAAs and test them to the simulated environment. In parallel, the h/w CAA can also be tested in the Simulator so as to verify the execution of SNNs in hardware.

Stage 4: Evaluation – Evolution

CAAs are evaluated according to measurement results and success criteria by the Evaluator. Then, the evaluator will produce the evolved CAA in XML code which comprises input to the CAA Builder and a new cycle begins.

A development process that implements the above model and which will be adopted in the project is illustrated in the following figure.

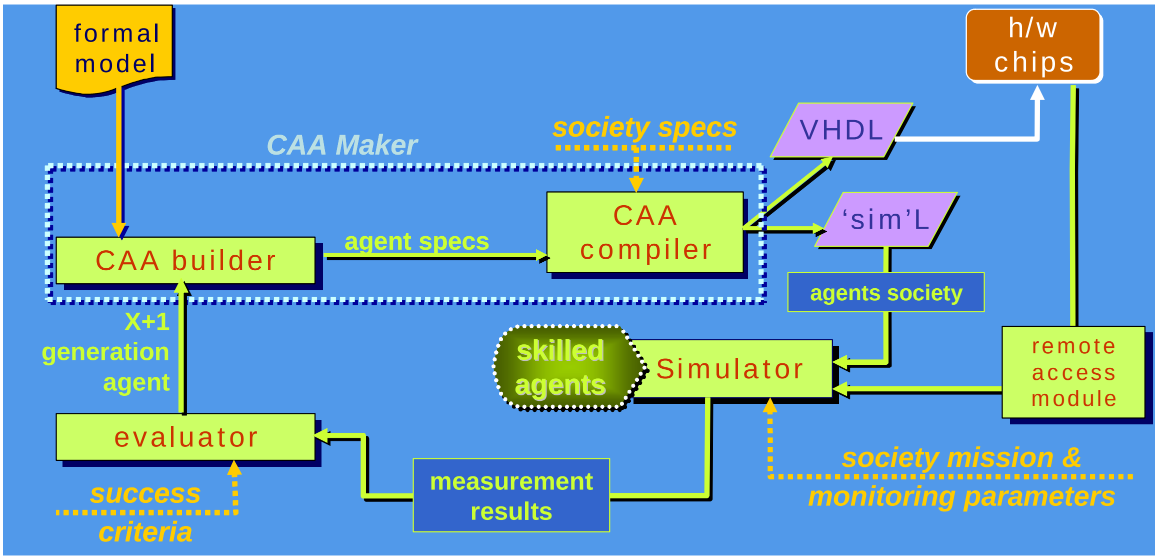

***Figure 1**: Development environment*

When all the necessary tools have been implemented (at the end of the second year of the project) a series of CAA generations will be produced. Then, based on the experience acquired, we will be able to propose a methodology that realizes the life cycle of CAA development. The methodology will be oriented and applied to the development of self-organized societies consisting of connectionist agents and will at least cover the following issues (as proposed by Colombetti, M., Dorigo M., Borghi G., "Behaviour Analysis and Training: A methodology for Behaviour Engineering", *IEEE Transactions on Systems, Man, and Cybernetics* 26 (6), 1996):

i) Identification of the relevant quality aspects for the product being designed,

ii) A method to specify the product to be designed

iii) Identification of the sequence of and the grounds for design choices that should be made and

iv) A way to assess the quality of the final product.

COMMUNICATION

In the SOCIAL project communication among agents is an essential concept that gives rise to collaborative behaviours. We adopt the classification defined by (Mataric, M. J., Issues and Approaches in the Design of Collective Autonomous Agents. *Robotics and Autonomous Systems*, 16(2-4):321-331, 1995) and hence we distinguish:

- **Direct communication** is a purely communicative act, one with the sole purpose of transmitting information, such as a speech act, or a transmission of a radio message. The message need not be symbolic, as it commonly is not in nature. Directed communication is direct communication aimed at a particular receiver. Such communication can be one-to-one or one-to-many, in all cases to identified receivers.
- **Indirect communication** is based on the observed behaviour of other agents. This type of communication is referred to as **stigmergic** in biological literature, where it refers to communication based on modifications of the environment rather than direct message passing (Kennedy, J. Eberhart, R., *Swarm Intelligence*, 2001, Morgan Kaufmann Publishers).

Agent to Agent communication

Agents communicate in order to better achieve their goals or the goals of the society/system in which they exist. Note that the goals might or might not be explicitly known to the agents, depending on whether or not the agents are goal-based. Communication enables agents to coordinate their actions and behaviour resulting in phenomena such as cooperation and planning, or competition and negotiation (Huhns, M. N., Stephens, L. M. Multiagent Systems and Societies of Agents. In G. Weiss, editor, *Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence*, MIT Press, 1999). In the case of direct communication, the agents are usually cognitive and the communication action is deliberate. This requires agents to maintain models of each other as well as to maintain model of the environment. However, such abilities require *computational resources that do not scale well with increased group sizes* (Mataric, M. J., Designing and Understanding Adaptive Group Behaviour. *Adaptive Behaviour* 4(1):51-80, 1995) and one of the focal points of the SOCIAL project is the engineering of emergent collective behaviour of large societies. Although mental primitives and models of other members of a society are appropriate for a number of applications and situations, they are not suitable in themselves for understanding all aspects of social interactions. Such limitations may lead to radically different approaches in order in studying situated domains where the agents cannot be assumed to be rational due to incomplete or nonexistent world models and models of other agents, inconsistent reinforcement, noise, and uncertainty. Undoubtedly, coordination and (in particular) self-organization are desirable properties for the agents of the SOCIAL project to have.

Direct communication is difficult to achieve with the targeted industrial fluidic environment due to the limited transmission ranges, bends in pipelines, shielding effects of the pipes. One way of attempting direct communication could be to install sensor, transceiver or repeater units in the pipeline walls. Obviously such fixed installations are costly to install and maintain in the industry. Even if direct communication of the CAAs was feasible then there is still the location problem, whereby the CAA detecting the fault needs to directly communicate to the other CAAs the fault location. In this closed environment of a metallic pipeline the tracking of location is a difficult problem without again installing hardware in the pipeline walls. Due to the aforementioned limitations of the direct communication approach in the context of the SOCIAL project, indirect communication (and a sort of stigmergy) is preferred because we aim at: i) **simplicity**, to design simple agents (with no cognitive states or models of the world) and reduce communication between them, ii) **incremental construction**, each agent contributes only a part of the whole solution, iii) **optimization**, a new solution is constructed from previous solutions, and iv) **flexibility**, when the environment change the agents respond appropriately to those changes (see also Bonabeau E., Dorigo M., and Theraulaz G. *Swarm Intelligence: From Natural to Artificial Systems*. Oxford University Press, 1999).

Indirect communication can be implemented by coding “quorum sense” signals as 802.11b beacon frames. The signals will have a certain transmission range depending on the CAA’s transmission power and receiving “sensitivity”. The transmitted signal’s gradual attenuation will create the desired “gradient field” around the CAA that emits the quorum signal. In the first generation of CAAs only one type of quorum signal is transmitted. However, subsequent CAA generations may be able to transmit different types of quorum signals. Different signals will facilitate the dissemination of more accurate and more detailed information among the CAA society, thus contributing to the improvement of the overall collective behaviour (e.g. locate the fault faster, gather at the faulty area quicker, etc).

In order to create such a differentiation in signals of the indirect communication, three possible modulation techniques are examined:

1. Signals are distinguished from their content.

2. Signals are encoded using different transmission power (which affects the transmissions range).

3. Different signals are transmitted periodically using a different frequency for each one[2].

Agent to Development Environment communication

Direct communication is not used for inter-CAA communication but for the communication of every individual CAA with the Development Environment, exploited for the monitoring of the tangible CAAs into the target fluidic environment. Specifically, the CAAs will be transmitting their ids, which will be used for the estimation of their location. The development environment will then use the calculated locations of CAAs and through the Simulator module will display the tangible CAAs inside its virtual environment. This will enable the observation of the motion patterns of the CAAs, which will in turn lead to a) estimating the behaviour of the CAAs both as individuals and as a society and b) evaluating, with certain success criteria, their individual and collective performance using the Evaluator module, thus comprising a real-time monitoring-evaluating operation. As a result, faulty CAAs, undesired behaviours etc. can potentially be detected and lead to actions such as replacement of CAAs, reprogramming of their SNNs etc.

For the location calculation it is proposed to evaluate direct RF communication of the CAAs, making use of the circuitry already included in the CAA for indirect communication, with receivers embedded in the walls of the actual environment demonstrator. Location estimation using a technique such as RSSI (Receive Signal Strength Indication) will be investigated and, based on the accuracy of results achieved, this may also be combined with another scheme such as inertial tracking or sonar to achieve a more accurate coordinate. Once the CAAs have been developed sufficiently then they can be deployed in a real environment where direct communication is no longer necessary or practical.

[2] in this case the use of an id is required so that the receiver avoids confusing received signals

TARGET APPLICATION

One of the important technological problems in secondary oil production is scale formation. The problem varies in severity depending on the composition of the make-up water used in water flooding. Scale deposits consisting either of calcium carbonate or Calcium and Barium sulphate cause clogging in the pipes and damage to the pumping systems because of the formation of tenacious scale deposits. The process of calcium carbonate is accompanied with proton release in the fluid and subsequent pH drop, according to the scheme:

$$Ca^{2+} + H_2CO_3 \rightarrow CaCO_3\downarrow + 2H^+$$

Calcium carbonate deposits tend to form around various nuclei of foreign material. Bulky and tenaciously adhering calcium carbonate deposits are formed in riser pipes used to control water level in secondary oil recovery processes. Moreover these deposits are encountered in heater-treatment units, i.e. storage tanks in which water is heated to be used for raising the temperature of the produced fluids facilitating the breakdown of water and oil emulsions in order to achieve separation of the two fluids. The process of steam-flooding of high-viscosity oil reservoirs involves also heating water in tanks. Hardness leakage through the ion exchangers usually employed, in combination with the bicarbonates in water result in the formation of calcium carbonate scale that result in dramatic reduction of the heat transfer coefficient. As a consequence rupture of the high pressure tubing has been reported.

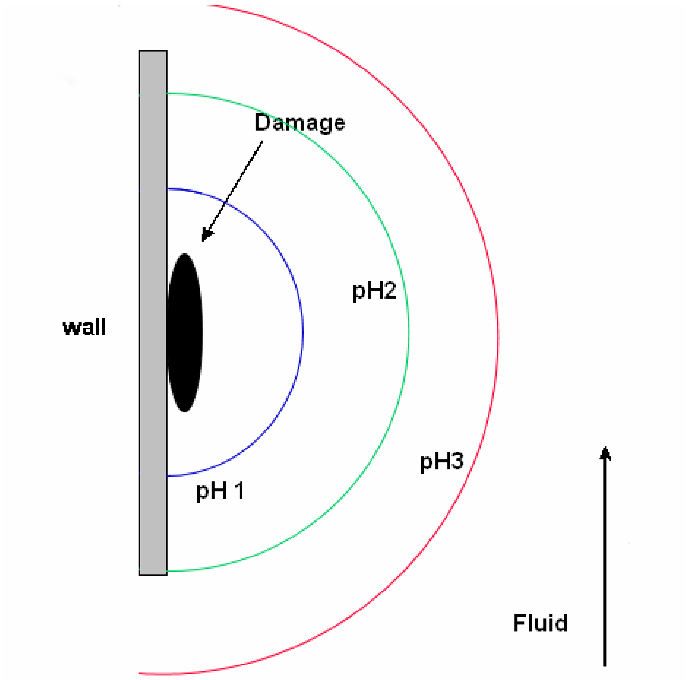

Figure 2: *Representation of the damage incipient on calcification. As a consequence of the formation of scale, local pH drops and the signal is transmitted to the pH sensors that record pH values depending on their spatial distribution with respect to the damage.*

Investigations on the formation of scale deposits in industrial systems indicate that **the slower the fluid velocity** the more intense the scaling problems due to the formation of insoluble salts like calcium carbonate [JC Cowan and DJ Weintritt, Water Formed Scale Deposits, Gulf Publ. Co. Houston Texas, 1975, pp.223-226]. Quasi static conditions imply no flow or very slow flow velocities.

In industrial environments very often, both for testing and operational purposes bypass pipe tubing used in fluid systems. These can be either very corrosive or have a tendency to form scale deposits on the pipe walls. The pipe loops are used either for having an alternative route for the passage of fluids when a particular section is malfunctioning because of scale formation or they are used for materials testing. For certain time periods the fluid is allowed to pass through the bypass section, after which the particular section is isolated entrapping fluid that remains at static conditions until the next period of use. A loop in a pipeline used in the oil industry is shown in Figure 2:

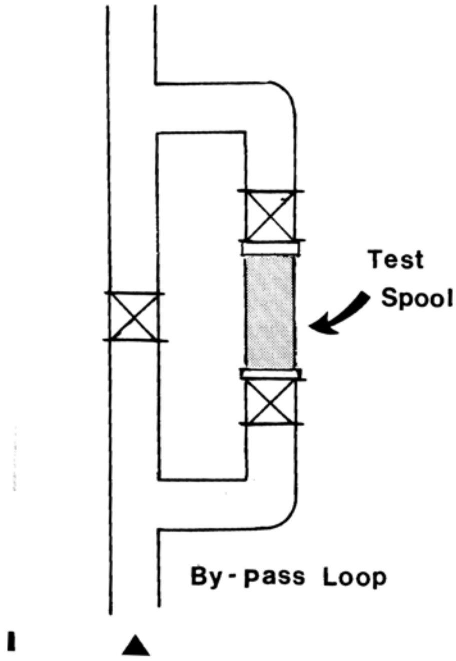

Figure 3: *By-pass loop used in the oil industry for testing materials and for alternative fluid direction*

SCENARIO

Agents circulate in one compartment of the fluidic environment, continuously sensing for "fault signals". The "fault signal" i.e. the environmental stimulus that signals the presence of a faulty element will be an altered chemical/physical property e.g. pH/conductance. A variety of sensory devices (i.g. ISFET PH sensors) are currently commercial available for these purposes.

When an agent perceives a "fault signal", it moves towards its source (i.e. the fault area) and simultaneously releases a "quorum sense", which ultimately "attracts" other agents: when any of the other agents perceive the quorum signal, they move towards its source (i.e. the agent having perceived the fault signal) and also start emitting the quorum signal themselves. Modulation of the emission of the quorum sense signal is contingent upon the local value of the fault and quorum sense fields, but also critically depends on the path the individual agents have traced in the environment as this is reflected in the spiking history of the neurons that sense and actuate the generation of the quorum sense field. As quorum signals are summed more agents are eventually attracted towards the fault area; when a quorum signal threshold is exceeded a spatio-temporally ordered community is formed, which starts repairing the fault. When agents repair the fault the strength of the original environmental stimulus drops, quorum signals diminish and hence the community disperses.

In the SOCIAL project we will empower individuals with indirect quorum sense communication by giving them an *actuator* that emits a properly modulated wireless signal; a corresponding *sensor* detects the signal emitted by other agents. The inherent capability of the CAAs to perceive and emit different signals related to an environmental change as described above, falls within the concept of indirect communication.

DEMONSTRATOR

The demonstrator envisioned for the end of the 3rd year is composed of the following elements.

Actual Environment:

A *cylinder* (diameter: 0.5 m, length: 2.0m) filled with fluid, quasi static flow.

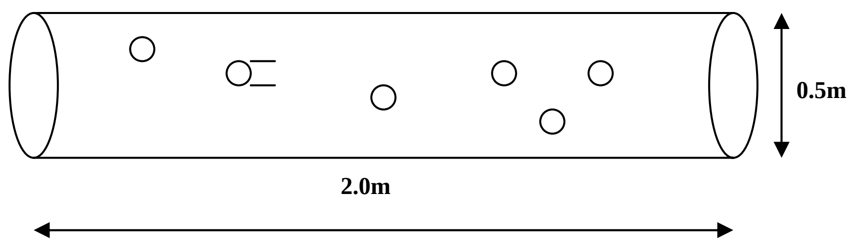

Figure 4*: Schematic representation of proposed actual experimental environment*

Fault:

Consists of $CaCO_3$ formation which generates a change in the concentration of protons (pH gradient)

Agent:

Sensors:

- pH: For example ISFETs (3 x 3 mm) mounted on spherical cell will be evaluated.
- Orientation: An option is a one axis rate gyroscope (solid state) embedded in the core hardware.
- Proximity: A photo-sensor array around the agent to detect collisions and avoid obstacles is an example of a method that will be investigated.

Actuators:

- Buoyancy control: regulating an artificial bladder or a syringe mechanism.
- Propulsion: to achieve movement the use of jet or thrusters will be investigated.

Core hardware component targeted for system integration into the miniaturized platforms:

- SNNs Implemented on FPGAs
    1. SNNs that receive voltametric readings from sensors
    2. SNNs that control actuators
    3. Computational SNN, also supporting the interconnection ("bridging") of the other two SNNs
- Communication subsystems: "Comms module" also known as "Communication layer" should contain the transceiver and antenna for direct communication and also the components for indirect communication along with microcontroller, crystal oscillator and power regulator. The "comms" module is an RF layer capable of supporting 802.11b. For indirect communication minimum functionality of the full 802.11b is required. For direct communication extra functionality is required to

support the transmission of larger content (e.g. id, location). Direct communication needs the extra layers of 802.11b (CSMA/CA and CTS/RTS) that ensure no packet loss will occur and that complex content is processed properly. The investigation on the feasibility of RF communication inside fluidic medium using the RF chip (Nordic nRF2401; 2.4 GHz) already incorporated in 25 mm cube shows that the module can communicate with another module under water. The preliminary results show that it able to transmit and receive data in a range of 30 cm only. Above 30 cm range the signal is highly attenuated.

- Power management system.

The HYDRA [http://hydra.mip.sdu.dk/] system will be investigated as a possible solution to the motion control in the agent architecture. An estimation of the architecture of the Agent based on the HYDRA actuator systems and the 25mm sensing, computational and communication modules along with some technical specifications of the various modules are given in the appendix

Appendix

Physical Agent Design

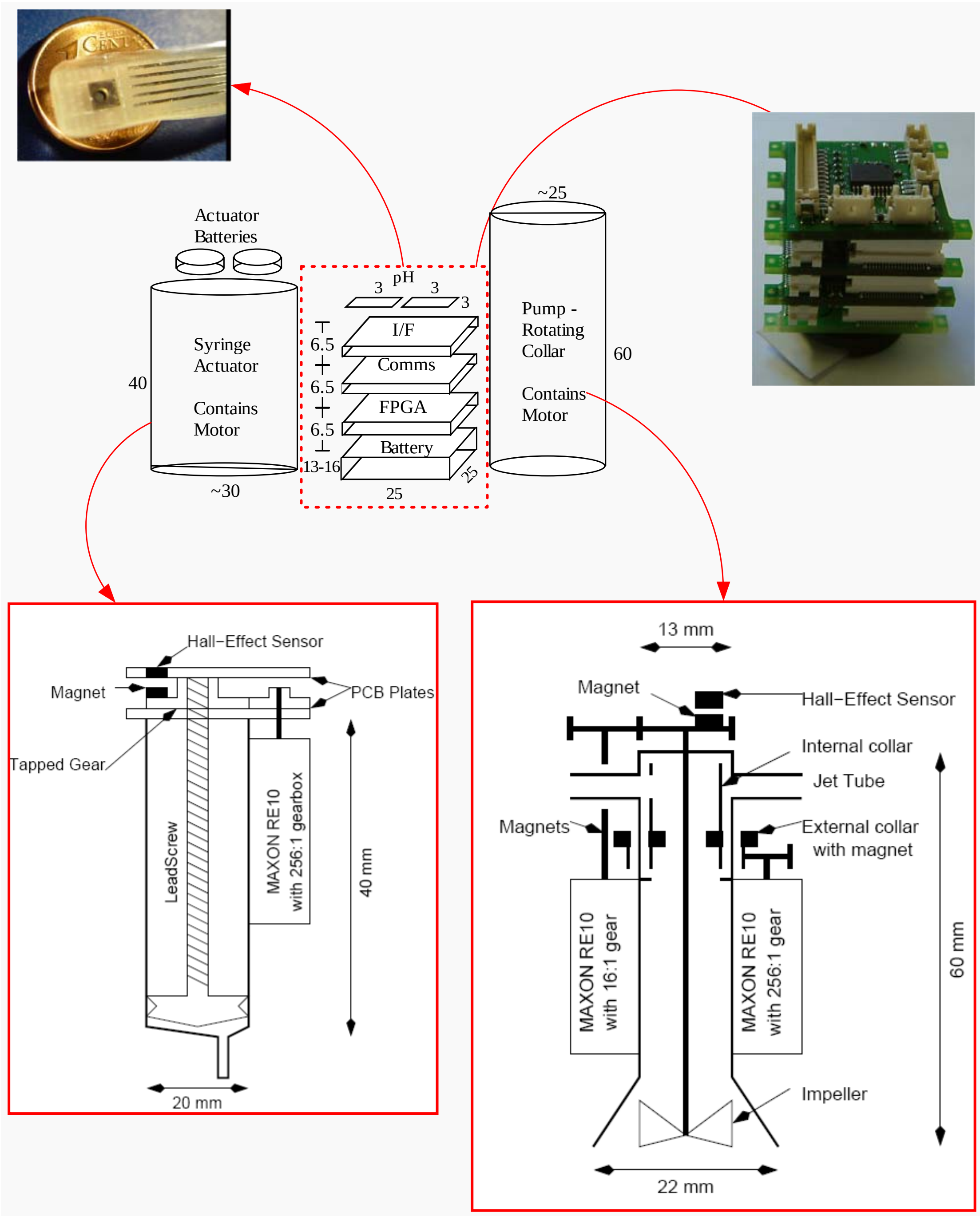

Figure 5: *Tangible Agent consisting of sensors, 25mm core modules and actuator systems to navigate all 3 axes:*

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CAA architecture will consist of 3 actuator systems to move the agent in 3 axes:

1. The Pump using a small boat impeller. Rotary drive to the pump impeller is magnetically coupled from the drive motor, eliminating the need to seal a bearing against ingress of water.

2. The rotating collar, which permits pumped water to flow along one of the jet tubes, propelling the Agent away from that direction. The collar is actuated by rotating an outer collar which is magnetically coupled to it.
3. The Syringe, which trims the buoyancy of the Agent, allowing controlled vertical movement.

The pump and rotating collar can be assembled in a common cylinder with 60mm length and approximately 25mm diameter. On the other hand the syringe actuator is about 40mm length and 30mm diameter.

All the actuators are driven using 0.5W MAXON RE10 motors with appropriate planetary gearing.

The actuator systems are based on the HYDRA [http://hydra.mip.sdu.dk/] project and can be considered as the worst case in terms of size for the SOCIAL project.

Moreover, since the battery layer in the 4-layer stack is not adequate to drive the actuators, extra batteries are required.

Finally, the packaging aspect is something which is important as it will ultimately determine the minimum overall size of the Agent.

25mm Core Components Module

1 FPGA Module

The FPGA PCB contains a Xilinx Spartan IIE Field Programmable Gate Array (FPGA) [1]. The Spartan IIE 1.8V FPGA family gives high performance, abundant logic resources, and a rich feature set. The device integrated into the 25mm PCB series is the XC2S300E-7FG256. This is a mid-range device with density of up to 300,000 system gates. Features include dedicated block RAM, distributed RAM, programmable I/O and DLLs (Delay-Locked Loops) for minimization of clock skew. The module features an on board 4MHz crystal oscillator chosen to give a moderate processing rate while conserving power. 1.8V & 3.3V low drop out power supply regulators to provide the maximum module lifetime from a coin cell battery attachment for the core & LVTTL IO voltage requirements respectively. The module also features an on-board Flash serial EPROM such that the FPGA configuration memory is automatically downloaded on power-up. The stackable connector system used allows simple connectivity to other modules such as the RF module, coin-cell power supply and sensor modules.

2 Communication Module

The current version of the 25mm transceiver module consists of a fully integrated frequency synthesizer, a power amplifier, a crystal oscillator and a modulator (Nrf2401 Single chip 2.4GHz Transceiver) [2]. Output power and frequency channels are easily programmable. Current consumption is very low, and a built-in Power Down mode makes power saving easily realizable. The module also features an on board antenna. The embedded microcontroller is based on the ATmega128L, an 8-bit microcontroller with 128K bytes in-system programmable flash [3]. The user can easily program the device with custom protocols for use in his end product or for general product development. This programmable transceiver has been designed to connect with a separate battery module and FPGA layer depending on the configuration required by the end user or his mobility/portability requirements. The current version of the module will be modified to implement the wireless communication mechanisms defined. Chipsets with appropriate footprint sizes, such as the Texas Instruments TNETW1100B Embedded Single-Chip MAC and Baseband Processor available in a single chip 12x12 mm BGA type package [4] or RFMD's 802.11b chipset having a reference design circuit board module measuring 27mm x 25mm [5], have been identified and timely supply of such critical components is currently being investigated.

3 Sensor Interface (I/F) Module

This PCB is a wired communication and sensor interface to the FPGA module. The current version contains a dual channel RS232 transceiver, the Maxim MAX3224ECAB in a small SSOP20 package enabling wired serial communication with a PC for test purposes [6]. The module also contains two TLC549CD Analogue to Digital (A to D) converters from Texas Instruments [7] for interfacing analogue sensors to the FPGA. The module also allows interfacing to seven external sensors of the type, which change their resistance according to the parameter being measured (e.g. Thermistors or light dependent resistors). The necessary conditioning circuitry for the sensors defined will be incorporated into a new version of this PCB.

4 Battery Power Module

Coin cells may be used to provide power to the 25mm system. A PCB has been designed to directly interface coin cells using the stackable connector system. A range of options exist for choice of coin cell including support for 20mm and 24.5mm cells. Single and double coin cell holders are also available. A future revision of this module will provide power management circuitry to prolong the lifetime of the CAAs.

5 Interconnection of modules

The modules use a stackable connector system to make the electrical and mechanical interconnections between themselves. These high density interconnect have 0.5mm pitch and are available in range of interlayer spacing from 5mm to 8mm to allow for different component heights on the PCBs. The connectors facilitate an 80 pin general purpose bus and a 40 pin bus for configuration and data transfer between the modules. The RF transceiver also has a 20 pin connector for 4 low noise analogue input channels.

References:

[1] http://www.xilinx.com/
[2] http://www.nvlsi.no/
[3] http://www.atmel.com
[4] http://focus.ti.com/pdfs/vf/bband/tnetw1100b_prod_bulletin.pdf
[5] http://www.rfmd.com/
[6] http://www.maxim-ic.com/
[7] http://www.ti.com/