AMBIENT HEALTHCARE SYSTEMS

Using the Hydra Embedded Middleware for Implementing an Ambient Disease Management System

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Abstract: Healthcare is an important aspect of ambient life. As the life expectation increases and thus diseases statistically become more frequent, the high-quality and cost-effective management of such diseases becomes a societal task. Within this paper we examine issues and requirements stemming from the implementation of disease management systems. Such systems critically depend on acceptance, cost-efficiency and other criteria that – through those requirements – are addressed by the Hydra multi-domain middleware. Hydra aims at the seamless integration of embedded systems such as bio-medical sensors and other domain-specific and generic equipment. We motivate and demonstrate the use of the middleware in the healthcare sector by means of a disease management system relying on the easy integration and proper configurability of applications running on the included measuring and controlling devices.

1 INTRODUCTION

From an economic perspective, healthcare is an evolving market. It constitutes a complex system with a plethora of requirements specific to each stakeholder, e.g. patients and their families, health care professionals, health care providers (public and private), governmental agencies and insurance companies.

This paper describes the application of technical means provided by the Hydra project addressing some of the emerging needs in the health care domain. The designed health care system particularly takes into account that people suffering from temporary, as well as chronic diseases, will make increased use of technologies that support continuous health monitoring, as well as care in terms of medication and advice, in order to mitigate disabilities and maintain, or even improve, their health status. Health care services will therefore have to be offered in an ambient way, e.g., while being in the domestic environment (Goubran, 2007), while being at work, on the move etc. Consequently, for medical devices to become a part of an ambient environment should automatically integrate themselves into the varying ambience of the user – nursing home, hospitals, work place or at home – so that biomedical data triggering appropriate activities can be seamlessly transmitted to background systems. Such activity could consist of alerting the doctor or nurse if a patient's bio-parameter (blood pressure, weight, glucose level etc.) changes critically.

Before describing the benefits of the Hydra middleware, background information on disease management systems in terms of the developments, requirements and solutions steering our efforts will be provided. Subsequently, the application of the Hydra middleware to a concrete application scenario that addresses the use of Hydra for dynamically connecting and configuring medical sensors, e.g. a blood pressure measuring device or glucose metering device, plus the software running on top of it will be described. Finally, some extensions and the key open issues that must be addressed in the future will be discussed.

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2 DISEASE MANAGEMENT

2.1 Major Trends

Currently the healthcare domain faces a significant change caused by the following tendencies:

- **Demographic change and aging population**: Developed countries have to deal with an aging society and growing life expectations. According to a report published by the UN's Department of Economic and Social Affairs (see UN report, 1998), 22% of the world's population will be *60 years or older* in 2050. Especially Europe will be affected as 35% of Europe's citizens will be 60 years or older. Senior citizens in particular will need medical assistance.
- **Environmental changes:**
  - **Urbanization:** More and more people are moving from rural areas into the cities because of comparably better job opportunities and a potential higher standard of living. *Negative environmental influences* in cities caused by local excess of population like air pollution will result in rising numbers of patients suffering from respiratory and other fatal diseases.
  - **Industrialization and climate change:** Since starting weather and climate recordings, experts have recognized a dramatic change of the climate and an increasing number of natural disasters due to increasing temperature on earth caused by CO2 emissions and industrial pollutions. On a long term perspective respiratory and cardiovascular diseases will potentially increase.
- **Cost pressure:** Due to the demographic change in the developed countries some social healthcare systems are seriously struggling, as decreasing or stable tax incomes cannot bear the increasing costs for healthcare caused by an aging society. In developing countries there is an increasing growth in population and therefore an increase in healthcare demand in total. Thus the demand and total *costs for medical treatments and assistance* have already started to dramatically increase.
- **New medical treatment and surgery methods and processes:** *New medical treatments* are emerging which result in patient-centric care at the cost of additional health care expenses.

2.2 Actors and Stakeholders

Besides these global trends and challenges, four groups of stakeholders have been identified in the healthcare domain. Each group represents different trends and challenges with respect to their objectives and tasks.

- **Patients** who require medical treatment are interested in participating in medical decisions and have an increased demand of preventive examinations like check-ups for cancer. A large share of patients is willing to pay more for health and also wellness.
- **Providers**, e.g. doctors, nurses, hospitals and nursing homes, which provide medical assistance and treatments, are facing exploding costs and capacity shortness. Therefore they have to optimize their resource allocation to achieve an increase in efficiency by applying new ways of medical assistance and care.
- **Governmental agencies** are struggling to ensure the quality of the national health systems albeit ever increasing costs.
- **Cost bearers** e.g. insurance companies, which compensate the medical treatment costs, are facing exploding health expenses and therefore looking for new ways to reduce medical treatment costs.

Nevertheless the demographic change and the enormous cost pressure harbour the chance for companies acting in the healthcare sector as service providers to introduce new concepts, like integrated supply, prevention in terms of medical wellness as well as assisted living. Especially health insurance companies and hospitals are looking for innovative concepts and IT solutions that help to keep costs as well as the rising number of patients manageable. Therefore disease management solutions that support assisted living, improve medical treatments, provide monitoring of patients and increase the efficiency within the health systems seem to be one of the most promising ways to reduce costs and to keep the growing number of patients manageable at an at least stable quality level of medical service.

2.3 Opportunities

Supporting ambient health care through technical means may definitely constitute a countermeasure to abate the increasing costs resulting from the above trends. The figures below illustrate the economic potential of disease management applications for monitoring patients' sensitive bio-data (see reference list).

- 33% of the elderly are interested in *assisted living services*, but less than 30% are willing to pay for such services. According to an US survey, 92% of people aged 65 to 74 and 95% of people older than 74 years want to stay at home instead of living in a nursing home. Nevertheless more than half of all 85 year olds need daily assistance (see BMBF 2008).
- According to the US Department of Health and Human Services *chronic illnesses* cause more than 75% of the medical care costs in the United States. In Germany for example the costs for diabetes and cardiovascular diseases amount up to 31.4 and 35.4 Billion € per year.
- The medical care of an Alzheimer patient costs 64.000 US $ a year in an US home for elderly people whereas a *home monitoring* would cost 20.000 US $. Daily costs for home monitoring would lie between 3 and 5 US $. The costs for a video based monitoring amounts to around 35 US $. In Germany 2 million people are in need of daily assistance. This causes yearly costs of more than 17 Billion €. Nursing home occupancy costs almost 4.000 € a month.

2.4 Key Functional Requirements

Especially elderly people and people with limited abilities who need daily assistance would benefit from ambient assisted living featured into the domestic environment. Such forms of assisted living at home require special IT systems which support functionalities to remotely control vital functions and bio data and enable health professionals like doctors and nurses to monitor and steer care processes. In order to do so, the systems consisting of devices, services and applications must

A. support to *seamlessly interconnect* devices like wireless sensors, medical / user devices and applications on top of them,

B. enable the *exchange of information* in various communication modes depending on a dynamically changing networking environment,

C. offer *convenience* such as detecting and handling a patient's context including critical conditions,

D. implement *safety* and *security* in the ambient environment though this is a rather broad topic particularly in the health domain.

When dealing with specific applications for specific purposes in healthcare, ideally such requirements would be covered (at least to a certain extend) by an underlying system platform.

2.5 Challenges

The above requirements are slightly more general than those mentioned in Stankovic et al. 2005. They result in several challenges for the system platform which will have to be addressed when compared to the state of the art.

Concerning A., a platform will have to deal with enormous device diversity. A huge amount of medical devices exist today. Some are equipped with wireless (I/R or Bluetooth, future devices may also support emerging standards like Wireless USB) or wired interfaces (USB, serial interface). For seamless integration, particularly bio-sensors will have to be modelled in order to be readily used. Also, it should be taken into account that multiple sensors will have to be handled simultaneously in case of multi-disease management. With respect to B., today it is still quite challenging to deal with the plethora of low-footprint (in terms of computing resources and energy consumption) protocols implemented on typical bio-sensors. Beyond multi-protocol support robust communication mechanisms in the platform will have to deliver advanced synchronisation mechanisms taking into account temporary off-line situations. Features for context-awareness (C.) will have to support federated or at least decentralized decision making which will have to be backed by central supervision. Especially for D., there are also reliability aspects which will have to be addressed by the platform for the sake of ensuring timely reaction in case of emergency and for monitoring the service level for billing and other purposes.

2.6 Sample Scenario

Our sample healthcare scenario addresses the proliferation of self-management schemes for long term diseases. Clinicians and developer users work together to bring about a wealth of smart devices and low power sensors in wireless, self configuring body networks which semantically interface to legacy health care systems. The systems are reliable and safe and doctors increasingly rely on access to remote information, not only to perform diagnosis but also in order to make long term risk assessments.

The statements above are reflected in a typical disease management scheme which is partitioned into the following elements:

1. **Device configuration**: before doing any measurements, the sensors and the other devices, including the applications, need to be configured in a convenient and preferably automatic way.
2. **Application configuration**: building on the configuration of the physical setup of the measuring environment, various parameters of the application such as conditions for triggering alerts will have to be defined. Such conditions may constitute a context which requires specific actions when reached.
3. **Monitoring**: in this part of the scenario, bio-data once sensed is automatically (i.e., with minimum user interaction) transferred to some background system recording the data and providing secured access to privileged users, e.g. the health professionals (physician). Completely different communication channels can be used for transferring the data, such as ordinary stationary Internet or asynchronous transfer via cellular networks through SMS for example.
4. **Data management and analysis**: in order to prepare for temporary off-line situations, data will have to be locally cached, thus transferred in bulk mode to be synchronized with the background system. Analysis of the collected data will be offered not only to the health professional but also to the adequately educated patient.

We will now describe how, by using Hydra, the scenario for the monitoring of the patient's blood pressure as sensitive bio-data can be implemented taking into account the requirements mentioned in 2.4. Adaptations to other types of bio-data (glucose level metering, weight measuring etc.) are straight-forward.

3 HYDRA MIDDLEWARE

3.1 Overview

Hydra constitutes a middleware for pervasive embedded and networked systems based on the service-oriented architecture paradigm. As one incarnation of this paradigm, web services promise a composable, interoperable, reusable and Internet-enabled wrapping of functions as services (Weerawarana 2005). Increasingly, this approach is currently extended to resource-constrained embedded devices like sensors in health care, which through implementing functions as web services become pervasive devices. Hydra faces some challenges in regards to implementing web services on devices which is prerequisite for achieving this interoperability. First, the web services should be adequately efficient in order to realise usable services on small devices, despite the fact that embedded devices are constrained in memory, processor and energy resources. Second, development of embedded web services must handle the variability of hardware and software, and possible dependencies between them. Especially, it has to be taken into account that the development effort may involve different implementation languages and communication protocols. Finally, there is the question of how to develop pervasive web service applications efficiently.

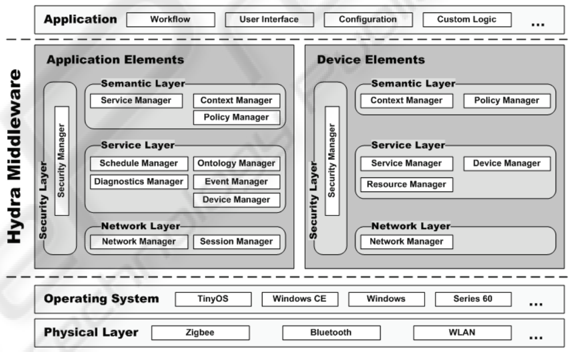

Figure 1: Hydra middleware Layered architecture.

In Hydra, the overall functional architecture is divided into two parts, namely:

- *Application Elements* (AEs)
- *Device Elements* (DEs).

AEs are meant to be deployed and run on comparably powerful machines, and DEs describe components that are usually deployed inside Hydra-enabled devices where small devices may be involved. The Layered architecture of the Hydra middleware is shown in Figure 1. From a deployment point of view the differentiation between the following physical entities is crucial:

- *Non-Hydra-enabled devices*, which do not host the Hydra middleware
- *Hydra-enabled devices*, which do host the Hydra middleware
- *Gateways*, special Hydra-enabled devices that incorporate non-Hydra-enabled devices in the Hydra network.

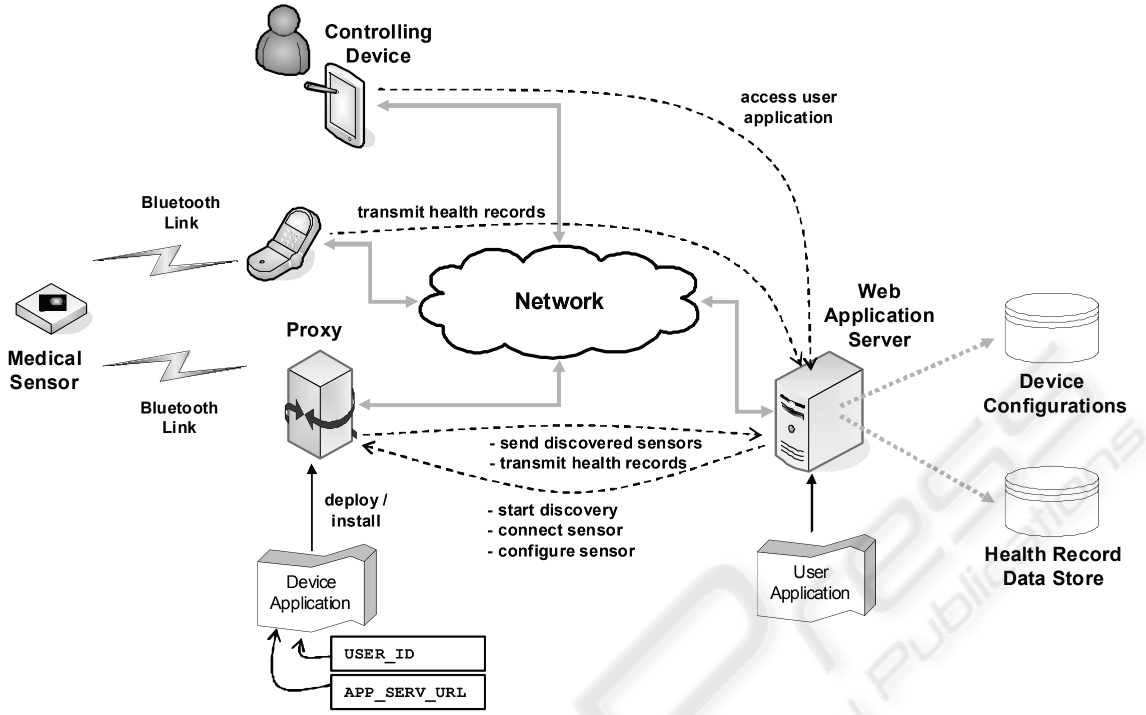

Figure 2: Architecture Disease Management System.

3.2 HYDRA Managers

According to Figure 1, the middleware comprises a set of managers, each of which is reflected in the AEs as well as in the DEs. The following managers make up the core middleware:

- *Network Manager* which handles the lower networking issues as part of the network layer
- *Service Manager* and the *Context Manager* on the semantic layer
- *Event Manager* which provides publish / subscribe functionalities on the service layer,
- *Device Manager* which constitutes a service discovery back end based on UPnP which offers the possibility of finding devices that support different communication protocols,
- *Ontology Manager* which permits one to describe devices (like medical devices and other equipment) on a semantic level,
- *Diagnostics Manager* which is used to monitor the system's conditions and states in order to fulfil error detection and logging device events.

Hydra also features a so-called *Virtual Devices* which is an abstract level on top of the above definitions of Hydra-enabled devices, Non-Hydra-enabled devices, Proxies or Gateways. Each of these devices can have at least one Virtual Device. Such devices are mainly foreseen to ensure *non-linkability*, i.e. to ensure privacy and security a malicious user cannot link to a device directly and thereby gain advantage via access to some or all of the communication running through the device. Virtual Devices are deployed on a different Gateway than the owning entity, thus changing the IP address.

Another purpose of virtual devices lies in the extension or limitation of devices' or services' original existing functionalities. A developer user or an end-user can decide to grant limited access to his device by offering only a minimised interface via the virtual device.

4 USING HYDRA

4.1 Featured Devices

Before explaining the deployment of the Hydra middleware to the various nodes in the Disease Management System, we introduce the actual devices featured in the sample scenario as shown in Fig. 2:

- *Measuring device*: We use the Corscience / Omron 705IT BT which measures the blood pressure on the upper arm. It is equipped with a Bluetooth interface for wireless data transmission. The measured value is automatically transmitted via a Bluetooth-capable cell phone or an approved Bluetooth modem to a central archive. A transmitted data record consists of the serial number, systolic and diastolic blood pressure values, pulse, time and date of measurement. Non-transmitted data is stored in the device. The transmission of stored data blocks is done at the time of the next measurement.

- *Gateway*: standard PC running Windows XP (laptop) with Bluetooth interface which acts as a proxy for the measuring device.
- *Mobile phone*: used as 2nd relay (alternative) to forward data to the background system. This relay is used in case the user is in a mobile context.
- *Mobile terminal*: laptop, PDA or Ultra-light computer used for configuring environment (either initially but also at runtime for configuring events etc.).
- *Application server*: hosting the application for controlling the environment and constituting a link to back-end services (e.g., storing medical health records).

4.2 Use of Managers

Figure 2 shows the devices and their interactions. The whole process of setting up the measuring environment is triggered by the *controlling device* which runs a web application (*user application*) hosted by a *web application server*. The web application server maintains data bases for storing the measured data and for managing meta-data (information concerning device configurations) with respect to the featured *sensor* and *proxy devices*. Moreover, the application server via some network is connected to the proxy device in both directions. I.e. once initiated by the user through the web application, it asynchronously starts the discovery of sensing devices on the proxy and takes care of connecting the selected sensor with the proxy, while also configuring both the sensor and the proxy. This requires that the device application that runs on the proxy has been previously installed. We assume that the device application is implemented as a service (*proxy service*), which has been personalized prior to deploying it to the proxy such that it knows about the user (via a unique USER_ID) and the URL of the application on the application server. The USER_ID has to match the code that is entered at the web application client on the controlling device. Thus there is a one-to-one relationship between proxy service and user.

According to the above scenario elements, the following HYDRA managers will be featured:

Device configuration:

- *Discovery manager*: during the configuration of the measuring environment, compatible devices matching the offered protocol (i.e., Bluetooth) will have to be identified.
- *Device Device / Device Service manager*: similar to other medical measuring equipment, the bpm (blood pressure meter) will provide the bio-data in a push / master mode which means that the device is activated and monitored bio-data is immediately transferred to a configurable data sink. Thus, the device will have to be proxified in order to offer push / master as well as pull / slave style interactions.

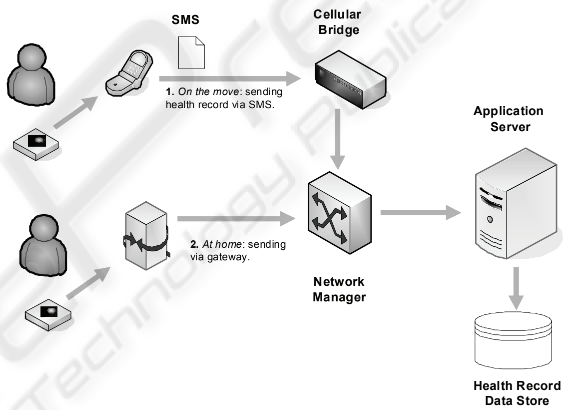

Figure 3: Use of Hydra Network Manager in Disease Management System.

Through the above managers, various parameters for the bpm can be configured, some will be changed *automatically* or through *interactive* user dialogs whereas others will be *simply displayed* and stored in a configuration database:

a. Current date & time (automatic)

b. Time zone (automatic)

c. Switch on / off buzzer (interactive)

d. Specification of Bluetooth pin (interactive)

e. MAC address (only displayed)

f. Identification (only displayed)

g. Serial number (automatic)

h. Firmware version (only displayed)

i. Use cellular phone as gateway (interactive)

j. Cellular bridge phone number (interactive)

Application configuration:

- *Context manager*: for the definition of conditions triggering an alert.
- *Event manager*: for creating events based on measured data.

Monitoring:

- *Network manager*: transfer of locally measured and stored (via proxy) bio-data to background system.
- *Context manager*: the monitoring process can make use of the dynamic networking and discovery / semantic resolution mechanisms of the HYDRA middleware. Through the context manager we can take into account varying user contexts (like 'on the move', 'at work' or 'at home') which require to dynamically connect the measuring equipment with other devices.

Data management and analysis:

- *Network manager*: used to exchange bio-medical data between application server and proxy (e.g., uploading analysis results).

On the other hand, the proxy calls the application server for registering itself with the application and upon finishing the device discovery. This is done during the configuration phase of the measuring environment. During the configuration phase the sensor (e.g. blood pressure measuring device) can also be switched to use a mobile phone in its proximity as a gateway for transferring the medical records. In the normal (sensing) mode the application offers a service for storing measured values.

5 SYSTEM USAGE

5.1 Application Pre-configuration

In order to simplify the configuration on the end-user site as much as possible, prior to configuring and using the environment some administrative tasks have to be carried out:

- A user has to be created comprising a unique User ID. In practical deployment of the scenario this would be done and administrated by a health care operator.
- The device application for measuring the blood pressure is adapted to the user by embedding the User ID into the device application. Since the device application is unique, an association between device application and user (through User ID) can be maintained. The personalized device application can be shipped either as CD, memory stick or offered as a downloadable software package via a portal.

5.2 Device Configuration

For the initial setup of the measuring environment, the patient uses a controlling (mobile) device that runs the user application provided by the web application server. The following steps are executed:

- Through the GUI of the blood pressure measuring application running on the controlling device, the user is advised to unwrap the delivery containing the bpm.
- The user is asked to ensure that the device application is properly installed and running on the proxy device. Moreover, the Bluetooth interface should be activated.
- The blood pressure measuring application asks the user to provide an *activation code* that comes with the package. A user might have to deal with several sensors and thus device applications. This unique code identifies the actual measuring process and is thus linked with the User ID and the application running on the proxy device.
  Depending on the provided code, some basic information on the bpm device is provided like for instance maintenance information or how to use the device or to what types of devices it can be connected (e.g., cell phone type)
- In this configuration mode, the user is advised to switch on the bpm.
- Based on the provided activation code, a session is opened. The user is informed that a Hydra Wireless Device Discovery is started on the proxy device. The discovery results are passed from the proxy device application back to the web application server. During the discovery process the user application is suspended for some time.
- The discovery results are presented in the user application. As the ordinary outcome of the discovery it will be shown that the bpm has been found. The user is asked to confirm the discovery result and permit the configuration of the device ('pushing the O/I button for longer then 5 seconds'). Because the bpm is usually in master mode, it advises the user to put it into

slave mode so that it can be properly configured.

Finally, the sensor is put into master mode again.

- After editing the according forms and storing the list of attributes on the portal, the configuration data is uploaded to the bpm via the Bluetooth link. The configuration settings are translated into a proprietary binary protocol offered by the bpm.

5.3 Measuring Process and Data Provisioning

On demand, the patient attaches the bpm to his upper arm and activates the device. The bpm, while being in master mode, measures the patient's systolic and diastolic blood pressure (including the pulse) values and transfers them together with the meta-data (timestamp, sensor ID, etc.) to the application server via the gateway. By analysing the user context (i.e., being 'on the move' or 'at home), the gateway is automatically determined. This can be done implicitly, because if the stationary home gateway is not available the mobile phone is used. The application server offers a service for storing health records together with a user ID.

When transmitting via the PC-based gateway, the Network Manager is used to send the patient records to the application server. When using the mobile phone, the bpm triggers the mobile phone via AT commands over the Bluetooth interface. The mobile phone then sends an SMS to a cellular network interface attached to the application server where the message is unpacked, and the service storing the health record is supplied with the according information.

6 CONCLUSIONS

Triggered by the shift from reactive and interventional healthcare towards prevention, systems supporting ambulatory monitoring and treatment of people suffering from long term diseases are gaining increased interest. Wireless sensors in clothing, shoes etc. yielding bio data will leverage possibilities for mashing up entertainment and supervised self-care. This will eventually become part of everyday life (Lin 2006). We have discussed some issues arising from the functional (e.g. interoperability) and non-functional (e.g. cost-efficiency) demands for such systems. Through Hydra we can devise solutions that thanks to the modular approach help to address these demands. In fact, Hydra permits to develop cost-efficient web-service enabled pervasive devices, such as bio-sensors by automating the process of generating lower level software constituents dealing e.g. with device discovery, communication management through the use of the built-in Hydra managers. The three layer approach in the middleware ensures structured application design and future extensions (through additional managers).

Future iterations concerning the use of Hydra in the health care domain, as well in other domains (building automation and agriculture), will yield indicators on the effectiveness of the approach. It will turn out if Hydra can be established as a platform for Health Care ecosystems integrating foundation as well as third party services.

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