CUBIT-type architectures for intelligent, reconfigurable sensor networks in aircraft and aerospace environments

Martin Dudziak
TETRADYN
martinjd@tetradyn.com

In this paper my aim is to present first an introduction to the CUBIT sensor-diagnostics-response architecture and how it has been designed, and secondly a brief set of suggestions for how this can be applied directly and economically into the aerospace industry, focusing upon commercial air passenger and cargo transportation and the risks of biological contamination that can spread throughout a population of passengers, workers, and visitors to air traffic facilities.

Introduction – An Overview of the CUBIT Technology

The CUBIT architecture was designed and implemented primarily with public health in mind, specifically addressing, in its phase-1 development, transmissible infectious diseases in human populations and in food supplies. "CUBIT" is the name of a cohesive product suite that encompasses bioelectronic devices, software, analytics, informatics, and technical services for health and safety providers and users. The acronym stands for "Coordinative (systematic, comprehensive) and Unified Identification and Intervention of Threats to Biosystems." It has also been described as simply, Coordinated Unified Biothreat Intervention and Treatment. With its several components, CUBIT is known publicly as the CUBIT Suite.

CUBIT is first of all a paradigm, a model, and an architecture for solving problems that are emergent critical processes (ECP) – events and series of events that arise with nonlinear and self-emergent properties and that conduct themselves in nonlinear and highly unpredictable, non-deterministic behaviors. Examples of ECP can include but are not limited to: influenza outbreaks, hurricanes, tornadoes, earthquakes, forest fires, food-chain contaminations, riots. An ECP is not necessarily negative in its effects upon people and the environment, but more often than not we as a society and as a scientific community are faced with ECP of a traumatic and life-threatening nature. CUBIT is focused upon those which threaten both the lives, happiness and economic stability of communities through diseases that, whatever the microbiological taxonomy, tend to affect large numbers of people suddenly and unpredictably. Nonetheless, the CUBIT architecture can be applied directly to topics such as wellness development, reduction of obesity, and many positive practices that benefit from sensing, monitoring, diagnostics and training within population groups large and small.

Functionally, CUBIT is implemented by using multiscalar and highly distributed methods of collecting data, performing analysis, and deriving responses for both medical treatment and social action (e.g., population control, food control). CUBIT is not an abstraction or theoretical framework only. As a deliverable product for a specific site and situation, it comprises a defined but flexible suite of analytical procedures, electronic instrumentation, bioassays, biosensors, antimicrobial bioprotection treatments, software, communication protocols, site monitoring and training. These incorporate specific hardware such as MEMS-based sensor chips, microfluidics, bioluminescence, and optical wave guide immunoassay sensors. The software is an evolution and integration of both conventional statistics with pattern recognition and learning derived from

Bayesian, inverse model, neural network, and thermodynamic algorithms. CUBIT aims to provide solutions for prevention, mitigation, diagnosis, reporting and response to biological threats to individuals and large populations that originate from natural, accidental or intentional outbreaks of biopathogens such as infectious diseases of bacterial or viral nature as well as predispositions and risk conditions exacerbated by IDLH chemicals, radiation, and other environmental agents and factors.

As described in standard contractual statements of work for clients, the CUBIT Suite is a flexible and integrated application of our biosurveillance, diagnostics, and incident response technology. Summarized in the following paragraphs, this comprises both hardware (sensing and monitoring), software, and antimicrobial treatment applications, complete with a tailored set of training, maintenance, monitoring and incident management services. These collectively ensure stronger ability and resilience on the part of an organization in dealing with many of the problems from infectious diseases facing our population, our workplaces, and our food supply chains.

◆ The **CUBIT Suite** encompasses and includes:

BioProt – facility bioprotection, antimicrobial remediation and Biothreat risk reduction

- analysis of present and past methods and incidents
- testing and monitoring
- antimicrobial surface bioprotectant treatment
- antimicrobial in-situ materials bioprotection
- staff engagement training
- facility and operations monitoring and follow-up

A key part of the BioProt process is the application of a quaternary ammonia salt solution to various surfaces (counters, walls, floors, furniture, machinery and other apparatus). The particular compound varies according to the surface material, and to the use of the environment. In some cases the treatment should or must be in-situ within the material at the time of manufacture. All of these issues are resolved as part of the BioProt procedures.

Wide-area and topical sensing and monitoring – this involves the use of enzymatic and colloidal gold reaction sensors, rapid antigen and immunoassay methods. These are devices that are used manually or in an automated configuration, and the samples may be from human bodily fluids, or from animal or plant material, or from samplings derived from exposed surfaces in, for instance, a processing plant, hospital, school, gym, or virtually anywhere. The objective here is detection and notification, not precise cell counts and concentrations, nor gene sequence analysis. Note however that the immunoassay diagnostic chips employed are very precise for particular strains of bacteria or viruses. The results of this level of sensing, observation and analysis indicate, for instance, what regions of a facility, what equipment, what food supplies or what members of a population segment need to or ought to be tested and cared for in greater detail, including with the use of "next-level-up" components in the CUBIT network. All of this is part of the overall principal of efficient completeness in performing a systematic analysis and response for a given facility, vehicle, community, etc.

PCR-based testing, diagnosis and knowledge dissemination about samples and the environments in which those samples were taken, for a variety of infectious diseases and medical conditions for which the PCR methodology can be used. This includes a platform-independent methodology, using a number of preferred, validated, and optimized "lab-on-chip" hardware components. TETRADYN and CUBIT are not bound to one single sensing or diagnostic method because of the variety of microorganisms and environmental factors (e.g., health-affecting chemicals) that CUBIT must effectively handle, in order to do exactly what it must, and which no other approach or toolset can accommodate. However, PCR, with TETRADYN's enhanced methods of doing PCR, is a key component.

RMMNP
There is also a new PCR instrument and assay methodology developed by TETRADYN and known as Reprogrammable Multiplexed Modular Nano PCR (RMMNP). This is TETRADYN's future nanotechnology. It constitutes enhanced PCR that will encompass an instrument and probe chip panels.

The probe chip panel is the heart of RMMNP and is what differentiates the TETRADYN solution from others on the market and that are known or suspected to be in development. RMMNP is a modular chip set, not one unit, and it allows more versatility and adaptability as well as improved performance in sensitivity, time and ultimate accuracy. The RMMNP is in an R&D stage presently, and in the interim, other PCR components (e.g., chip panels) are employed; all equipment and units are currently available, in production, and proven by field tests and approvals (e.g., FDA).

Additional Components
Within CUBIT are other deliverable programs that are not individual products for corporate customers such as a food processing plant, school system, transit authority, cruise ship line or hotel chain, but for integrated groups of public agencies and private companies together.

- A program of concise, clear management education on the current situations, risks, and options with respect to biothreats and bioincident response in an industry, with an emphasis upon both avoidance and prevention, and also response and continuity.

- A tailored, customized program of facility bioprotection, antimicrobial remediation and biothreat risk reduction oriented to a client's production facility (indoors, outdoors and transportation), staff, and supply chain, encompassing:

    - analysis of present and past methods and incidents
    - site, equipment, livestock (if appropriate) and/or staff testing and monitoring
    - antimicrobial surface bioprotectant treatment
    - antimicrobial in-situ materials bioprotection
    - staff engagement training
    - facility and operations monitoring and follow-up
    - business continuity preparedness and action plans

- In addition TETRADYN provides a plan for ongoing support and response by its specialist team and equipment in the event of either of the following types of events and situations:
    - biothreat incidents directly involving the client firm (onsite or in your supply chain);
    - biothreat incidents involving competitors and similars in the client's industry, events such as will create risks and bear adverse consequences upon the business if not properly addressed physically, technically, with proper communications and information dissemination;
    - other incidents involving chemicals, radioactive releases or risks thereof, explosives, acts of Nature or acts of terrorism and/or criminal intent.

- events in nature, society or the food supply chain such as can offer opportunities for the client firm, given TETRADYN's assistance and resources to assist, to gain and grow market share among the client's customer base through appropriate and timely public and direct marketing, advertising and other communications

◆ CUBIT encompasses several functions and how they are deployed for a given customer depends upon what is that customer, what is their business process, and how everything about their activity as a business (or non-profit institution/agency) relates to people and the possibilities of biothreats, direct or indirect, to their immediate population (workers, students, visitors, patients) or to populations that can be affected by their institutional activities (e.g., foods produced and distributed, mass-transit, medical care, schooling, etc.). CUBIT may be understood also as an application methodology for using sensors and human-machine systems and interfaces to have for biothreat and pandemic situations – and extending to other emergent critical events and processes - the equivalent in protection (analogous) to a DEWS system for ICBM nuclear attack.

A CUBIT installation or application would incorporate, typically, a Nomad Eyes implementation for SANER (situation awareness, notification and emergency response), plus preventive (prophylactic) use of bioprotection treatments (BioProt), and post-incident treatments as well, including extensive software integration of both TETRAD and 3rd-party products and interfaces. CUBIT also incorporates Pallas software methods, models and tools for the engagement, training, control, and monitoring of the relevant population (staff, workers, students, residents, patients, visitors, consumers). CUBIT also makes use of dRAKE countermeasure technologies and integrated solutions for active countermeasure response against sources and perpetrators of the substantive threat.

◆ What are some other components, derivatives, and constructs that make up the full taxonomy of the CUBIT Suite?

CRAIDO (Community RApid-Response to Infectious Disease Outbreaks)
aka Community Rapid-Response Infectious Disease Diagnostics Tracking and Reporting Mobile Network, aka CUBIT-Delta

Network of real-time multiplexed lab-on-chip PCR-based nodes for diagnostics of infectious disease onsite, in the field, mobile if necessary, and including the analytics and simulations for projecting detected mutation types and their epidemiological vectors into the populations at risk. CUBIT-Delta employs generation-1 PCR instrumentation and will employ TETRADYN's generation-2 PCR technology.

CUBIT Designer
Interactive web-based software (modules written in PHP, Java, C++ and SQL) for agents and responders to rapidly assemble teams of people and equipment for responding to a critical Biothreat situation. CUBIT Designer is the C^3I software engine that enables users to coordinate people, instruments, supplies, and specifically actions and transportation involving PCR instruments and probe chip panels, bioassay supplies, sample transit, and the optional use of mobile units employing PodLab (reconfigurable mobile laboratory) technology.

VSRB (Virtual Sample Repository Bank)

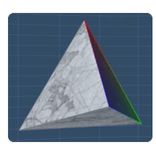
A derivative of CUBIT-Delta that is focused upon the tracking and dissemination of information pertaining to the location, conditions, availability and dispositions of selective patient samples of high-probability infectious disease agents (e.g., HxNy influenza). VSRB is a UNOS-like system for tracking samples (human, animal) of interest and for potential use in testing over and beyond initial pathogen identification.

◆ How are some other TETRADYN technologies and products used within the CUBIT Suite to bring the rightly-needed solution to both private and public sectors for fast response and treatment of biothreats? Consider these brief summaries.

dRAKE for/within CUBIT pertains to active countermeasures employable as part of some CUBIT installation or operation These are both AID (Anomaly and Intrusion Detection) and ASHES (Attack, Seizure and Hostage Expanded Security Countermeasures) functions. Examples include the use of stationary and mobile cameras, or sensors on MAV, UAV, AUV platforms, or deployment in a defense/security posture of more active countermeasures against intruders, terrorists, or infected wildlife.

NomadEyes for/within CUBIT pertains to SANER (Situation Awareness, Notification, and Emergency Response) functions. Examples include the use of NomadEyes cell phones and server-side software for collecting useful data (images, texting, and optional sensor data) and for distributing messages, advisories and warnings.

Pallas for/within CUBIT pertains to the activity, both electronic and in-person, remote and onsite, of studying, monitoring, training, and advising people who are in the CUBIT-relevant environment, such as employees, students, travelers, and visitors to a given facility or area. This is principally done through software including web-based portals and interactive social networks. Examples include training staff and visitors in hygiene techniques and in self-help monitoring of the physical environment, wildlife, suspicious behaviors, etc.



How CUBIT can be applied to Needs and Requirements in the Aerospace Industry

The CUBIT architecture was designed and implemented primarily with public health in mind, and not for any one specific type of community or industry. However, each of its major and also minor components, including: surface and in-situ material bioprotection, sensor networks, gene-sequence-specific diagnosis, and situation awareness notification, all have particular strong applicability for use in and around aircraft, airports, and the aerospace field in general. Some components have already been demonstrated for effective use in aircraft and airports. In this brief section, I wish to address how CUBIT as presently designed can be rapidly, efficiently, economically applied to problems facing air transportation both on the ground and in the skies, for both passenger and cargo air traffic. However, I will be particularly brief in my points here, since this is a very open-ended topic and the objective here is to provide an appetizer, so to speak, for having further and very concrete work performed.

Let us consider some of the risk pathways within commercial air traffic for harmful agents that may be of a chemical, biological or nuclear nature. (The focus is upon biological agents such as bacteria and viruses, but since other agents can be accommodated as well, through a modest addition or change in detector hardware and "tuning," it is worth mentioning that we are not limited to biopathogens only.) Therefore, there will in this paper be few particulars and specifics regarding pathogen types, but only some generalities, lest this paper become longer than it will be already.

Consider one or more H1N1-infected or H1N1-variant-infected [1]passenger(s) on a 12-hr. flight, particularly one that may be subjected to delays that bring many passengers into mixed, close confinement and also in an environment that is conducive to respiratory and laryngeal irritation, coughing, etc. Consider that by or before landing there are passengers with noticeable symptoms, and others who have been exposed in varying manners. An onboard immunoassay capability is within the constraints of a typical 747, 777, 787 design and crew capacity. Advance warning in the form of preliminary testing and diagnostics could enable more expedient preparations on the ground. Time and money saved, passenger discomfort reduced, and with less risk of infected carriers getting out into the mainstream population.

In the airport, a full-up CUBIT-delta node (station) with less than two hours' time between sampling and final diagnosis. This is manageable and sensible; having people sit and wait for hours, then taking a sample and either putting people into quarantine or sending them off with uncertainty on the part of all, these are not satisfactory at all.

Now let us address pathogens such as MRSA, norovirus, e.coli, salmonella, and others that can be transferred from a person to some object and then to another person. This is a very common route of contamination and infection. In both the aircraft and throughout the airport, here is where CUBIT's surface bioprotection process applies. Antimicrobial protection for the critical contact and exchange surfaces, at no greater cost than for a thorough cleaning and repainting. This is the classic "no-brainer" in terms of public health economics. It is a prophylactic measure that has a long life and proven returns on the modest investment incurred. The same antimicrobial bioprotection can be applied to the HVAC system, without any major change or labor on that HVAC equipment. At the same time, regular and also stochastic monitoring with sensors is important. This is not high-end PCR but low-end SWIPE-type and stand-off spectroscopic sensing. Strain-specific accuracy and detailed counts are not what is needed, but a high-level understanding of what and where are different infectious agents and what constitute risk areas that in turn demand attention from the aircraft or airport environmental health and safety staff.

Consider now the problem of contamination in cargo containers of fresh produce that is transported by air. A class of small credit-card-sized sensor units can be employed for spot checking or for physical insertion into containers; the sensor element can be used in a completely manual method or else linked with wireless communication for transmission of readings to an internet server. For instance, the CEBIT sensor developed by TETRADYN employs an array of piezo-resistive microcantilevers (PRMC) for detection of particular molecules for which the

---

[1] Consider a mutation between H1N1 (highly transmissible, lower lethality) with H5N1 (very high lethality) – this is one example of a mutation that we face as a planet in 2009 and this can lead to tens and hundreds of millions of deaths worldwide.

MEMS chip has been tuned and pre-set electrochemically. With an array of 8 to 32 elements, it is possible to use one sensor chip to monitor conditions for several types of biopathogens as well as other chemicals such as explosive agents. One compact device can be used to test for several targets of interest. This versatility and reconfigurability opens up tremendous opportunities for checking and cross-checking what goes into, on and finally off aircraft, and it can be applied to any type of cargo containers and methods of shipment.

Perhaps one of the most valuable features of CUBIT for aircraft and airports is that the devices and the software are highly interchangeable, platform independent, and also fault tolerant. Redundancy is built-in deliberately. CUBIT is based upon sensor fusion principles, and this links in strongly, fundamentally, with the NomadEyes distributed stochastic network architecture that was designed, before CUBIT, as a means of linking together highly disparate and "normally uncommunicative" types of data collection and transmission, including consumer cell phones, into a network that brings together images, sounds, and sensor readings for the purpose of assembling and "painting" a whole picture of an environment with respect to chemicals, biologicals, and other (e.g., nuclear, radioactive) materials of concern. What this means for the operators of an aircraft or a facility such as an airport is that there is as much diversity and quantity in sensing data as there may be people (both employees and the general public) and devices such as cell phones, PDAs, and custom sensing devices. All can "talk" a common language for delivering objects of data, all of which are potentially interesting and relevant but none of which will require special demands or create unacceptable risks in terms of false positives and false alarms.

CUBIT, and the underlying NomadEyes algorithms used in its knowledge acquisition, inference, and decision processing, is extraordinarily open-ended, in keeping with the fundamentals upon which the internet and the web have been designed and have evolved over the years. There is no allegiance or dependence upon isolated, proprietary, "special case" protocols or interfaces. If a device such as a sensor is useful because of what it can do physically, and if there is no immediately available way to have this device "talk" with the network, then there is a place for some middleware to create that bridge. In this manner, the end user and his/her community (airline, airport, public health agency, etc.) are protected from the classic trap of being locked-in with a technology that is "hard-coded" and demanding upon the rest of the system to accommodate its idiosyncracies.

Parallelism and redundancy are quite at the heart of how biology works and succeeds. Intelligence in the brain and throughout the organism is inseparable from doing, trying, experimenting with different ways, different procedures, different perceptions and their evaluations. Life Itself is constantly trying out many lock-key combinations in parallel, all at once, quantum mechanically and at the macro scale of complex motor behavior. Nowhere in biology is there a classical machine that never changes itself, never experiments, never evolves. Therefore, why should we not listen, watch, and learn from our own biology and our own environment, when it comes to matters such as protecting our people, our goods, and our vehicles of transportation from one form of biological threat or another, be that a microscopic virus whose very nature, whose "essence" is to mutate and change, over and over again, or a group of bipeds of our own species who have chosen to follow a "viral" calling to destroy others among us?

In conclusion, I am of the firm opinion that the type of stochastically behaving and complementary reporting networks of sensors, probes, and actuators that comprise a CUBIT-style approach to both closed and open environmental health and safety are precisely what will be excellent enhancements for aircraft, air cargo, and air facilities. This is not something that requires years more of thinking and researching. Doing so in the "vacuum" without the actual field operations and space-temporal "live experience" factor is precisely what is not needed. A CUBIT architecture could be designed and implemented into an aircraft straight away, in the remaining months of 2009, or into any existing airport facility (Frankfurt am Main is one rather receptive such airport), or better yet, into both. I have given you here a very simplistic and rough outline. The mathematics, the formalisms, the algorithms, and the physical devices, these all exist, they work, they have worked, in more than one setting. Putting them together into one cohesive organic system is something that can surely be done today. The requirements are simple, and again, for emphasis, economical. I am certain that a functional fieldable system can be built and demonstrated within an existing institutional budget, given the obvious needs, the interests, and the risks associated with not pursuing these sorts of improvements for our air safety and public health.

Author:

Martin Dudziak, PhD
Chief Scientist, TETRADYN
http://tetradyn.com
757-847-5511
202-415-7295
martinjd@tetradyn.com
martin.dudziak@gmail.com