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A Contribution to Considerations of the Role of Embedded Systems

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Abstract

Background: Embedded systems are a ubiquitous part of modern civilisation. Trends point to further intensification of their use. In this article we discuss long-term implications of that process, from the point of view of systems science. **Objectives:** On a general level, we relate embedded systems to a general class of objects and argue about their role in human life. On a somewhat more specific level, we consider in more details the development of unmanned aerial vehicles. **Methods/Approach:** In order to achieve the set objectives, we conducted inductive theoretical considerations and presented the results in this section. **Results:** The hierarchy of notions relating human civilization to environment is established, and embedded systems are positioned within it. **Conclusions:** Broadening and intensification of the use of embedded systems is a gradual process, heavily intertwined with societal changes. The case study of the development of the unmanned aerial vehicles reveals the potentials of the concept of embedded systems, also in the area of human resources management.

Keywords: embedded systems, environment excitations, dissipative structures, unmanned aerial vehicles, human resources management

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Introduction

In contemporary technological development the embedded systems are an often encountered notion (Pejić Bach, Stepanić, Strugar 2012). Embedded systems are computer systems designed to function in a specific way as a part of some larger system. As computer systems, they combine both the hardware and the software parts. All statistics and predictions point to rapid future increase in their use, both in quantity (BCC Research, 2012; Lakka et al., 2012) and quality (Jerbić, 2007; Pejić Bach, Stepanić, Strugar, 2012).

The propulsive character from the one point of view implies intense dynamics in the corresponding market segment. From another point of view it enables one to argue that their development is a characteristic of some deeper, more general structure and dynamics of our society (Parr Rud, 2011), which is especially important in the era of digital divide (Pejić Bach, Zoroja, Bosilj Vukšić, 2013).

In this article we concentrate on the later point of view and address in some details the very meaning of embedded systems. The article is organised as follows: second section describes general notion of elementary excitations, third section provides some details and conclusions regarding application of that notion to embedded systems, fourth section treat a specific example of unmanned aerial vehicles as a representation of an embedded system, while fifth section concludes the article and lists some perspectives.

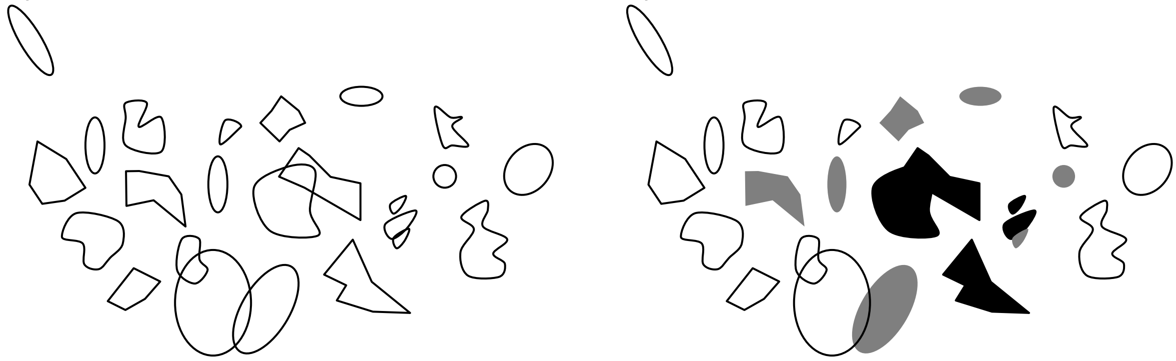
Elementary Excitations

Let us consider environment of some system as a collection of excitations. Environment excitation is defined within a system's value set, as a separate part of environment. The stated separation can be attributed to characteristics like material from which it is built, shape, duration, etc. In fact, we assume that whole environment can be partitioned, and considered to be a set of environment excitations. Here, the number of types of these excitations depends on the referent value set (Stepanić, 2004). In attributing the notion of environment excitation, nothing is implied about the way how it is obtained, either "naturally" or "artificially". Before proceeding, let us remark that the very notion of environment is not unique for all members of that system by itself. Indeed, for systems, some of elements function as environment for other elements. Nevertheless, the very definition of environment does not interfere with the approach of excitations, to be presented further in the text. Because of that, we do not impose a precise definition of environment.

Not all possible environment excitations are utilised significantly by the system. On the contrary, one may argue that a system utilises a small number of these excitations. In general, environment excitations cover too broad set of objects and processes, realised or imagined. If one wants to relate further environment excitations to human system dynamics, a further analysis of environment excitations, as recognized in some system, is needed. Within the collection of environment excitations, let us extract elementary environment excitations (Stepanić, Bertović, Kasać, 2003). Out of the set of environment excitations one may extract a subset consisting of the excitations which are attributed a specific function in the referent value set. Elements of such a subset are called the elementary environment excitations (EEEs). Figure 1 illustrates listed notions using parameterisation of the environment with some unspecified variables. Fig. 1a shows possible environment excitations, direct consequences of environment dynamics. Fig 1b shows that some of the environment excitations (denoted as grey shapes) are recognised by a system, and some are extensively used by a system (denoted as black shapes). Grey shapes represent environment excitations and black shapes elementary environment excitations form the point of view of the system's value set.

Figure 1
Relations among environment, system and excitations

a) b)



Source: Authors' illustration

The elementariness of some environment excitation represents functions attributed to the excitation within a system value set. For example, a computer, a mobile phone, an aircraft, an unmanned aerial vehicle, ... are for a considerable amount of time the EEEs in many societies. These are examples of EEEs that are considered to be artificial, in that they are not spontaneously present in a natural environment. In fact, the structures which we consider to be part of our environment, in general are elementary environment excitations: food, wheel, furniture, buildings, words, news, ...

The adjective elementary, along with other introduced notions, should be described based on the underlying system's value set. Elementariness implies that the emphasised EEE has a unique function within the value set. In addition, elementariness implies that the corresponding EEE is the least part of environment performing the given function. Let us for completeness remark, somewhat poetically, that every value set is a separate universe, having a particular dynamics which, henceforth, induces changes in EEEs. In aforementioned text we did not make a distinction between the material and immaterial EEEs.

Value is one of quantities defined within some system. It is general EEE's characteristic. Several factors influence contribute to the value: availability and cost of the EEEs components, cost of labour needed to bring about the EEE, demand for it, its durability, etc. That does not mean that a value has u unique, unequivocally numerical expression in the system's value set. Rather, the value is well represented as a distribution of numerical expressions with different probability of encountering it in the system. Similarly, function(s) of an EEE does not have to be widely known. It is sufficient that they exist within a subset of a system, usually consisting of specialised institutions.

Another notion which is of interest in this article is the notion of dissipative structures. A dissipative structure is a structure which needs energy transfer with environment in order to preserve its structure. It was introduced within the analysis of nonlinear, complex systems, in a highly formalised approach. Here we use that notion conceptually.

For completeness, one has to address in more details human contributions to stated notions (Merkač Skok, 2013). First of all, value set referent for some system is formed by humans. Secondly, the very transformation of environment excitations into elementary environment excitations is conducted by humans as a result of research, innovations or other similarly nontrivial processes. Thirdly, regular activities and regular dynamics involving EEEs as a rule needs human operators, contributors or other modes of human involvement. Development of EEEs is as a rule gradual, despite the seemingly sudden aspects of its development that are usually extracted and considered as representative facts. Therefore, an important aspect of human involvement is long-term correlated cooperative work which on the one hand includes inter-generational transfer of knowledge as well as intra-generational transfer of best practices and newly gathered knowledge and experience (Merkač Skok, 2010). Thus a human regulator is needed who prescribes modes of operations of involved humans that are to be accepted. Naturally, that is usually the same, implicit non-specified collection of humans that contributed to development of a value set of the system in question, since that value set contains prescription of stated processes.

Embedded Systems as Elementary Environment Excitations

Having in mind that stated about EEEs, let us consider the embedded systems. Their function in environment (usually considered as a larger, otherwise unspecified computer system) is to perform some function, such as is pre-processing, sampling, measuring, sensing, providing temporary power transfer, etc. Their elements include processing unit (a microprocessor), unit for connecting with larger system (serial or parallel cables, wireless connection, etc. with accompanied cards), one or more units for connecting the embedded system with environment (sensing unit in a case of a sensor or an instrument, or actuator in a case of a control unit). All these units include hardware and software for proper functioning. Moreover, in order to function properly, embedded systems need energy, as a rule in the form of electric energy. While their hardware is observable without power supply, their software is observable only if there is a power supply in the embedded system.

The elementariness assumes some relatively large time interval passed during recognising the function of an environment excitation. Within a system, therefore, elementariness of an environment excitation is invariant in time when checked within a time interval the duration of which is comparable to characteristic time unit of that system's regular dynamics.

Characteristics of embedded systems vary in time. What is nowadays an average embedded system was in recent history, e.g. a decade ago, considered as a powerful computer. It is reasonable to expect that modern powerful computers are of similar characteristics as will be some average, future embedded system. In that sense, embeddedness is a relative category. We discuss in more details the differences between an embedded system as an environment excitation and as an elementary environment excitation. The embedded system as an EE means that within the group of other EEEs, like computers, automatic machines, robotic devices, control units, etc. exists some which have common set of parameters. In this specific case, such parameters are, among others, characteristics of a microprocessor (clock, cache, average power consumption), and other parts of the system hardware, as a rule mounted onto a common board so that the hardware is visually clearly separated from the rest of environment.

In the phase while embedded systems are considered as an EE, and not an EEE, their characteristics are numerically different from characteristics of other computer systems. However, the differences are not considered as defining a separate class. It is expected that during such a period, functions of embedded systems have been conducted with computer systems which, from the point of view of modern and well-optimised embedded systems (thus, the embedded systems as the EEEs), were either too powerful for the relatively moderate functions that they had to perform, or too simple (e.g. manual or semi-automatic systems in which a human operator had to regularly interact with the system conducting some of the predicted functions). In that sense, the development of the understanding that there is a separate class of computer systems was a gradual, organic process, including alignment of many variables. In particular, as was stated previously, in case of embedded systems, both the processing capabilities and the electric power consumption characteristics, needed mutual adjustment in order for the introduction of a separate class to have sense. One may argue that, as in the case of other EEs, the simultaneous development of the environment needed to take place in the form of new requirements and rich enough structures so that a sufficient number of applications were needed.

Therefore, in the development of embedded systems, one extracts three phases: first is the phase of EE, secondly there is a transient phase in which there is non-negligible, but also non-prevailing view onto embedded system as on EEEs, and thirdly a phase of developed notion of the embedded systems as EEEs. The first and third phases are considered non-transient. That does not mean that they are static, but that there is a well-defined, prevalent place of embedded systems in a societal system's value set as either EEs or EEEs. These two phases can have, and do have as can be seen, intense dynamics on different time and space scales within a system. Yet, because there is no change of experience of the embedded systems we consider that the notion of the embedded systems is invariant in time and place during first and third of listed phases. Time invariance is here introduced as a characteristic of the rules which determine exchange processes. In particular, time invariant rules do not change in time because of some unspecified cause. Duration of an EEE is related to the possibility to accurately and precisely characterise it. The longer the duration, the more accurate and precise the EEE's characterisation. Conceptually, space and time characteristics of an EEE has been discussed previously (Stepanić, 2010) The spatial characteristic of an EEE is the characteristic dimension of the part of the system in which its characteristics does not differ significantly. It is in order to stress the difference between such a description and the more straightforward description of a spatial characteristic as the total region within which some EEE is recognised.

Space and time invariance of elementariness provides additional insight into the system's value set. That set can be considered as a collection of elementariness attributes. In that sense, set of EEEs serve as a shield, or as a generalised clothes that humans have developed in order to align the society and themselves to the environment. It is a dynamics structure, in which some excitations develop and enter the generalised clothes, while other are abandoned, cease to be utilised and are gradually forgotten or in other ways not utilised within a societal value set.

The very development of embedded systems is not discontinuous as may be inferred from dividing it into three phases. Rather, the boundaries of the phases are vague, and probably non-uniquely introduced. The overall achievement of a system by developing embedded system is better adaptation to its environment, as each and every embedded system through performing its function and conducting its predicted dynamics, serves as an infinitesimal contribution to better adaptation. Second phase is usually interpreted as emergence (Stepanić, 2010). The object or process that emerges is the one as stated in phase three.

Case study: Development of Unmanned Aerial Vehicles

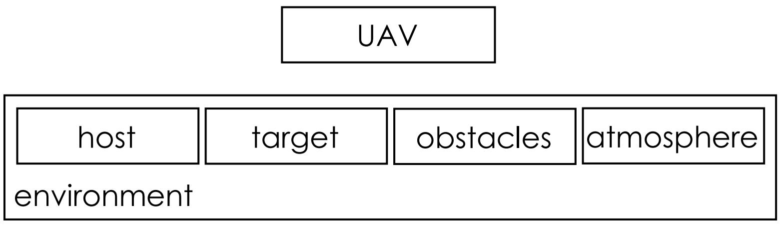
Unmanned Aerial Vehicles (UAVs) are objects that fly without carrying a human pilot during flight. Along with a necessary logistic support, e.g. ground facilities and/or other aerial communication and navigation systems, they form Unmanned Aerial Systems (UAS). Their development started during World War I (Taylor, 1977) and has been linked to defence applications since then, and in somewhat smaller amount to commercial applications as well. In recent years and, according to predictions (Cambone et al., 2005) in near perspective, their development is of considerable proportions both in quantity and quality.

There are several characteristics of their development: (i) there was clear set of functions that they should conduct, (ii) their initial development was subject to stringent available time and affordable costs. Regarding (i), set of functions imposed, one can observe that the functions were related to defence activities: the UAVs were figuring as aerial targets for training fighter pilots and anti-aircraft gunnery batteries. Additionally, they were considered as aerial torpedoes, i.e. the remotely piloted or autonomous bombs. Soon, their reconnaissance role became important. Because of (ii), they were developed starting from the maximal utilisation of existing solutions and minimal interventions on the existing devices. Their gradual development of evolutionary character has been bringing about qualitatively new solutions. In that sense, development of UAVs follows the development of initial inventions followed by a sequence of innovations (Frenken and Leydesdorff, 2000).

Let us emphasise here one characteristic of UAVs – there is no human pilot, or other personnel on board. Thus, from the very beginning, if UAVs were to reliably represent enemy targets, to have non-trivial flight trajectories, they were forced to be developed as autonomous (more precisely: semi-autonomous) vehicles. During first several decades of their development, they were prevalently remotely piloted, using radio-connections and simple underlying protocols. However, having in mind that auto-pilot was patented during WWI, there were early attempts to use (non-digital, non-computer) systems enabling the UAVs to have a non-trivial level of autonomy. Thus, when electronics, and further the digital electronics, reached a sufficient level of development, it was readily implemented for control system of autonomous UAVs. It is interesting to note that UAVs were called the robot aircrafts in previous decades (Taylor, 1977).

On general level, UAVs are a set of EEEs. They differ in principle utilised to fly, in shape, propulsion, dimensions, purpose, ... but they all share the function to conduct some transfer of mass, energy and information while flying. Such diversity in their characteristics contributes to the fact that their classification is not a universally adopted characteristic (Ćosić et al., 2013). During the initial development phase, UAVs manifestly resembled references that their designers started from. The UAVs, as we refer to them, started as planned projects to fulfil clear needs of a society's important institutions. Therefore, initial development of UAVs belongs to the phase two of previously listed EEE development phases. First phase is in fact out of the scope of sketched historical development and covers timeless use of model aerial vehicles, toys, which predated development of manned aerial vehicles on the one hand, and which exist nowadays in their own niches of RC toys, models, prototypes etc. In that sense, from this example, it is conjectured that first phase in development of an EEE in fact covers situations during which that EEE is completely different EEE, with different function and with assumed, maybe occasionally discussed additional functions. Naturally, these additional functions are discussed and tested as exceptions, not as a rule. The fact that quantitatively values of parameters describing e.g. an UAV during its phase of EE and of EEE differ, here is of no significance. Within the set of UAVs as contemporary EEEs in their third phase of development, there exist larger differences in values of some of their characteristic parameters, than between the UAVs and other EEEs such as manned aerial vehicles, of unmanned vehicles for other environments (underwater, ground, etc.). Stating that development of UAVs brought about their recognition, thus making them EEEs, does not mean that their development is finished. Indeed, similarly like other structures contributed to emergence of the UAVs as EEEs, the very UAVs further may contribute further to development of additional EEEs. In other words, from the very titles that initial UAVs were referred to (the aerial bomb, flying torpedoes), and from the very origins of their components (along with previously given examples, let us include aircraft wings and engine as well as radio control unit into that list), one may address the presently existing differences in UAVs as precursors of EEEs that still did not emerge in a widely recognised form. One may conjecture that UAVs predicted for surveillance can bring about additional objects, UAVs predicted for harvesting energy from atmosphere another type of objects, UAVs predicted for transport of objects yet another type of objects, etc. all such objects being in fact further EEEs. The development of further EEEs from existing UAVs is not spontaneous as it requires material and immaterial means to develop a new functional form.

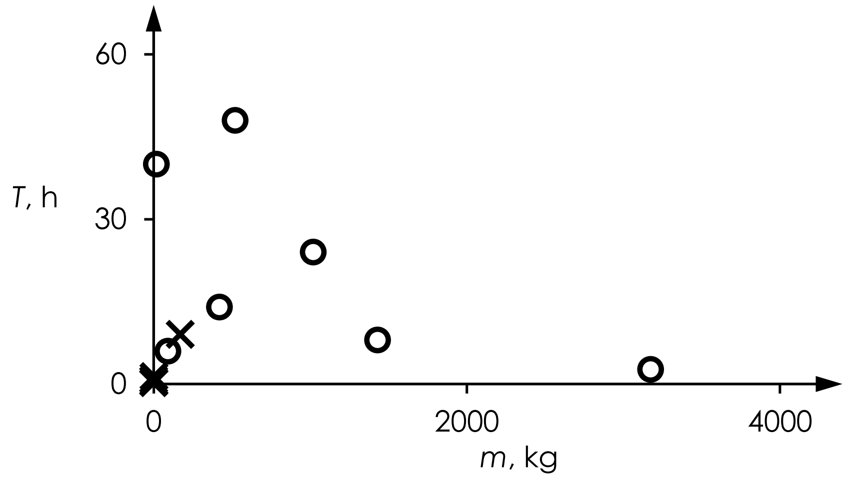
Figure 2
Unmanned Aerial Vehicles and Main Elements within their Scope



Source: Ćosić et al. (2013)

The UAVs are now in phase three of previously described phases of EEEs. Outlined historical context of their initial development points to the complexity of causes of their emergence. The variable intensity of particular utilisation of UAVs, creation of new and new niches for their use, all point to the fact that within the class of UAVs as a set of EEEs one may extract separated additional EEEs. Time and space framing of UAVs, following the similar considerations for a general EEE (Stepanić, 2004), is bound to the social systems using them. The development of digital electronics, thus of embedded systems hardware and software, erases boundaries between previously existing EEES. One example of that are planned modifications of previously manned aircraft in order to obtain UAVs from them. Another example is the gradual intensification of the use of auto-pilots, the systems for automatic flying. In past they were used occasionally and exceptionally for a moderate number of purposes. Nowadays, they are used as default interrupted with pilot's interventions. Such systems are usually realised as Fly-by-wire and Fly-by-light systems. During flight of an aircraft with pilot, these systems constantly take part in regulating specific elements of flight control. Mentioned examples illustrate the tendency to broaden the use of embedded systems in aeronautics, both qualitatively (introducing new functions and new specific systems) and qualitatively (more and more aircrafts and UAVs are produced with a high level of the use of embedded systems). Yet, the diversity of functions for which the UAVs are developed enable one to argue that out of the UAVs in future one may expect development of further EEEs, well separated in functions. As an illustration of that point, Fig. 3 presents current situation regarding the power-plants of UAVs. Since different power-plants influence considerably the overall flight duration (as well as some other UAV's characteristics as maintenance costs) one may argue that presented differences will gradually develop further in future probably bringing about well separated UAV types, i.e. further EEEs. In Fig. 3 each symbol marks one of representative modern UAVs, the details given in Ćosić et al. (2013).

Figure 3
Relation of UAV's Flight Duration (*T*) to their Mass (*m*) for 2 Types of Power-plants: Crosses Denote the Electric Motors, Circles the Fossil-fuel Engines.



Source: Ćosić et al. (2013)

In order to function as an aerial object, an UAVs needs energy transfer between it and its environment. Let us concentrate on that fact from the point of view of dissipative structures. UAVs with propulsion (e.g. UAVs with fixed wings resembling unmanned aircrafts, or UAVs with solid and rotating wings resembling rotorcrafts) need fuel for their engines. Such UAVs conduct work on their environment in order to fly. UAVs without propulsion, such as balloons, need initial work conducted on them in order to bring them into the buoyant state. That state degrades in time interval usually larger than time interval needed for UAVs with fixed or rotating wings to come to ground in case of engine stop. Thus, in case that they do not have additional power to restore buoyancy, the buoyant UAVs function during time of their degradation. For the buoyant UAVs, the environment conducts work on them and thereby brings them into the flyable state.

Similarly to general analysis of EEEs, let us analyse human contribution to UAVs, in particular through approach of human resources. These are involved in several ways: first the humans invented and developed UAVs, along with the underlying principles governing them (e.g. principles of aerodynamics). Thus, creative human resources are of importance for that part. Secondly, humans utilise UAVs as operators in UAS. Naturally, humans are part of other systems extracted from environment in Fig. 2, as well as part of yet uncharacterised environment as given in Fig. 2. Furthermore, humans conduct maintenance, repair and overhaul as purely operational contributions encountered regularly within aeronautic technics and engineering, preserving the functionality of UAVs and of total UAS. Moreover, humans are needed in order to realise latency of the development and utilisation of UAVs: knowledge and especially experience gathered before and during one human generation needs to be transferred to next generation of UAVs users and developers. Training and education, along with low-intensity longer-term unstructured tutoring during work, all contributes to conducting stated activities. In that sense formulating requirements for humans who will efficiently and successfully use UAVs share some general requirements imposed on human resources extraction & development as well as some specific ones.

Conclusions

Embedded systems are a representation of elementary excitations, a notion introduced on a general level describing interactions and adaptation of a system to its environment. The elementary character of the excitations means that their function is defined as well as recognised within a crucial part of a societal system.

The richness of dynamics of overall development of computer systems point to the fact that the dynamics of its part, the embedded systems, will also be of significant richness. One example of applications of embedded systems are unmanned aerial vehicles. They are elementary environment excitations formulated on the one hand within a highly propulsive area with a significant innovation potential, and having on the other hand clear societal functions and demand.

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