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3 authors:

Biljana Risteska Stojkoska
Ss. Cyril and Methodius University in Skopje

Kire Trivodaliev
Ss. Cyril and Methodius University in Skopje

Slobodan Kalajdziski
Ss. Cyril and Methodius University in Skopje

Internet of toys: state of the art and future applications

Biljana Risteska Stojkoska [*], Kire Trivodaliev [*], Slobodan Kalajdziski [*]
[*] Faculty of Computer Science and Engineering (FCSE)
University "Ss. Cyril and Methodius", Skopje, Macedonia
biljana.stojkoska@finki.ukim.mk, kire.trivodaliev@finki.ukim.mk, slobodan.kalajdziski@finki.ukim.mk

***Abstract*— This paper provides a comprehensive definition of "Internet of Toys" as a new application domain of "Internet of Things" including both sociological and technological aspects. We survey available Internet of Toys architectures from the literature and propose new architecture/framework that will enable interconnection of smart toys into complex entertaining environments capable of exchanging data, learning from experience, and obtaining new insight on children's cognitive development. Additionally, we determine the challenges inherent to the general Internet of Things, but also those that are specific for the Internet of Toys.**

I. Introduction

There are many examples in the children everyday lives of utilizing the state-of-the-art technologies, from using tablets, interacting with smart toys in complex learning environments, to humanoid robots that can fully simulate humans and monitor proper children development [1]. The main component of these applications is a "smart toy", defined as a toy equipped with processor, memory, and sensing unit, capable to detect physical phenomena and to react in a predetermined way. It can perform simple or more complex task, depending on its processing capabilities. Smart toy or intelligent toy does not necessary need to record the actions, or to transmit the recorded data or actions since most of the smart toys do not possess communication modules.

In the context of the emerging field of Internet of Toys (IoToys), "smart toy" consists of software that allows the toy to be connected online (through Wi-Fi and/or Bluetooth) or to other toys [2]. These toys are equipped with different sensors, and relate one-on-one to children [3], therefore the Internet of Toys can be divided into two general groups: IoToys that simulate human interaction (sensor-based toys, such as famous Barbie dolls with enabled voice recognition) and IoToys that do not simulate human interaction (toys-to-life). The most sophisticated toys (some robots like Cozmo and Leka) are not only smart and connected, but they can be augmented with programmable actions not enabled from the producer.

The term "Internet of Toys" appeared firstly in a conference paper [2] in 2010, and since than there has been other research closely related to but not extensively covering this topic. IoToys as a relatively new concept has appeared as a complementary sociologically based approach to the well-known and more popular concept of "Internet of Things" (IoT). Still, most of these state-of-the-art IoToys approaches that exist are specific to particular toy and create a particular learning/entertaining setting/environment. Since toys settings are not integrated into a common framework, the data gathered from one learning/entertaining setting cannot be exchanged or reused by similar, or even identical settings. There is a lack of common framework that will serve as guideline for integration of different smart toys setting.

Regarding challenges associated with designing IoToys solutions, only data privacy is largely covered in the literature, from generating and sharing data to the risks that data imposed to the kids involved. There are many challenges related to IoToys, like challenges coming from the main umbrella of IoT to more domain specific, but they are not yet identified and analyzed.

In this paper we aim to overcome the abovementioned gaps in the literature and to come one step closer to understanding IoToys paradigm. The first aim of this paper is to provide a comprehensive definition of "Internet of Toys" regarding all relevant sociological and technological aspects of this paradigm. Secondly, we will review the relevant literature and extract IoToys frameworks/architectures that are already proposed in the literature. Considering domain specific characteristics, we will extract all common features in order to construct raw architecture/framework that will be used as a solid base for interconnection of smart toys that are still not utilizing their full collective potential as IoToys. Additionally, we will try to identify all relevant challenges associated with developing IoToys solutions present in the state-of-the-art literature and determine the most important ones. This overview should provide a comprehensive roadmap for parties that aim to employ this paradigm for business, industrial, educational or research proposes.

To the best of our knowledge, this is the first paper in the literature defining the term "IoToys" from engineering and data science perspective, in contrary to other publication that cover the topic from educational and socio-economic perspective.

The paper is organized as follows. The second section describes the research methodology used in our survey. Third section summarizes the Internet of Toys architectures from the papers we surveyed, their historical evolution, state-of-the-art and future general framework. The fourth section provides in-depth analyses of the challenges present in developing successful IoToys solution, defining from technical and non-technical perspectives. This paper is concluded in section five.

II. RESEARCH METODOLOGY

To summarize the most appropriate recent developments covering topics that relate to the IoToys paradigm the published literature was searched using the online service Google Scholar (GS) (https://scholar.google.com/). Besides the obvious search term "Internet of Toys", other search terms, as shown in Fig. 1, were also allowed to appear anywhere in the text of the publication. The total number of articles found for each search phrase is given in the Fig. 1. The overlapping articles were further removed from the list. From the remaining articles, we used only those published in prestigious journals and conferences.

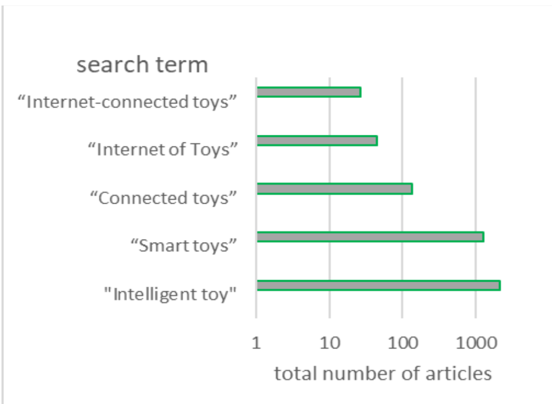

Figure 1. Total number of publications retrieved by GS using different search terms

Regarding the number of articles found with the search engine the results reflect the problem motivating this article. A lot of research is focused on toys that are capable of data processing and possess some form of artificial intelligence, however their intercommunication is rarely considered as a research problem. Furthermore, literature of smart toys integrated in an Internet of Things paradigm is even scarcer. Regarding the specifics of the Internet of Toys two main challenges arise from selected articles, and that are the interactivity of the smart toys and the data security and privacy issues. Other, no less important aspects that need to be properly addressed are big data issues, knowledge extraction, data reduction, interoperability, etc. [4].

III. IOTOYS ARCHITECTURES

In this section we are going to survey our findings from the literature. We consider a historical perspective of the topic, describing the process of toys evolution in the last few decades. We also define a common framework as a sublimate of the "state of the art" approaches, which is a solid base for future IoToys solutions.

A. IoToys evolution

The roadmap of "Internet of Toys" started almost 40 years ago, when first intelligent toys appear on the market. They were the first toys able to communicate with the children, i.e. to perform some form of interaction (Fig. 2 left). Since then, the toys evolved toward possessing more complex capabilities, allowing them to be remotely controlled with smartphones, tablets, or computers (Fig. 2 middle). The information and communication technologies (ICT) are the main enablers of this (second) generation. Other characteristic for this generation is the ability of toys to communicate with each other, which is the main feature of the concept "Internet of Toys", widely accepted in the literature [5]. So, the only requirement for the existence of "Internet of Toys" is the ability for toys to communicate and exchange data with each other. The last (third) generation of toys defines the most complex learning/entertaining settings/environments (LESE) where many kids can interact with many toys. The adults (parents/teachers) are active entities in this system. They can monitor the children and learn their habits, abilities and requirement with the help of the devices (Fig. 2 right). The most advanced state-of-the-art solution attempt to belong to this generation.

[6] reviews the aspects of parental monitoring of infants in a networked society. The infant wearables used for monitoring share the same context as the internet of toys in terms that both utilize Internet connections to provide personalized feedback and interaction and often collate a significant amount of information about the child. The paper states that the datafication and intimate monitoring of children is becoming a necessary culture of care and a standard for affectionate parenting. Following these societal norms parents often overlook issues like the lack of proper medical and/or scientific usage of the data collected and even more important the data privacy. The data captured, although anonymized in terms of personal information, is complex enough for individuals to be identified by finding appropriate patterns in the data itself.

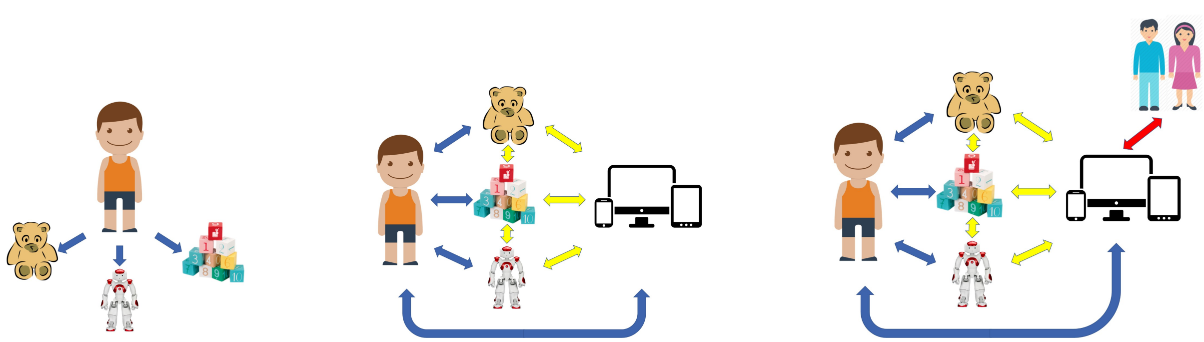

Figure 2. Three generations of smart toys

The authors of [7] investigate the educational promises that may be expected from the Internet of Toys. The study finds that young children are enthusiastic about digital affordances accessed through physical play objects, as they undertake a range of activities with these toys that foster play, creativity, and learning. Moreover, the conclusions indicate that the IoToys have the capacity to initialize social play and this can be considered both part of their digital and physical affordances, and their connectedness and digitally-enhanced features embed their educational affordances.

[8] introduces visible light communication (VLC) in networking toys and smartphones. VLC has a low cost of implementation using existing toy components, thus facilitates toy networking. Additionally, toys can easily communicate with smartphones using cameras and flashlights. The authors argue that with the IEEE 802.15.7, updates in the IrDA standard, and the lightweight IPv6 protocols developed for the Internet of Things, the free space optics can play an important role in providing an Internet of Toys at low-cost, without adding unnecessary complexity and/or resource requirements.

[9] describes the design and implementation of a sensor-base low-cost smart toy system that performs datafication of the child play. Data is collected by a mobile computing platform to be analyzed for developmental delays by professionals. The authors propose a centralized collector-based architecture that allows non-technical users to easily interact with the toys, perform different experiments and gather data without directly interacting with the underlying sensors.

[10] presents a study on both children's and parents' perspectives on toys that listen. The study is concerned with the models of interaction between the toys and both children and parents, and their expectations of the toys' intelligence. Furthermore, it examines the children's perception of their privacy while interacting with the toys, and parents' privacy concerns and expectations for parental controls. The findings indicate that children are not satisfied with the current interaction models which are not sufficiently sophisticated and that they are already exposed to other everyday devices that listen, like smartphones or smart home devices. The results for the privacy perception show that children are unaware that they recorded by the toy and monitored by the parents, while parents have mixed opinions on the toys' recording capabilities, but all agree in terms of privacy concerns and monitoring.

A ToyBridge is a middleware platform that integrates physical-world smart toys with online activities [11]. The communication between browser applications and external devices is via sockets. The ToyBridge-to-toy interface depends on the type of toy used. If the toy uses IrDA, the ToyBridge provides Visible *Light Communications (VLC)* technology. The Toy-to-browser interface enables the shifting of toy complexity to the computer, providing easy creation of applications that can make full use of smart toys' radios, sensors, and actuators.

The EDUCERE project investigates, develops, and evaluates innovative solutions for detection of psychomotor development changes in children, through their natural interaction with toys and everyday objects. In [12] the ethical impact assessment (linked to data protection rights) was carried out from the EDUCERE project. They applied smart toys for detection of development difficulties in children, but also, they provide and apply privacy protection measures (security concerns of children's health data) that consist of legal and technical measures. The authors have placed particular attention on the usage of the information about the transformation of bulk data (acceleration and jitter of toys) into health data when patterns of atypical development are found. By applying "privacy by design" paradigm they handle ethical and juridical prerequisites.

A Hello Barbie playmate applies Internet connectivity and speech recognition techniques to deliver a truly responsive and interactive experience, like two-way conversation, playing games, or even telling jokes. Children can develop a very strong connection with the Hello Barbie toy and can fed up the system with serious conversations like bullying, religion, and making friends. The authors of [13] tend to identify the sensitive personal information shared by children and propose a solution to balancing the right to privacy vis-à-vis the duty to report (the proposed amendment to COPPA, obliges companies such as ToyTalk to report about the reasonable suspicion of child neglect and abuse). The proposed solution aims to protect abused children without shackling smart toy manufacturers with heavy burdens and expenses.

The web-based Clinical Decision Support System (CDSS) [14] solves the problem of early diagnosis of language disorders in early detection of language pathologies. By using this monitoring tool, the nursery school educators can assess the degree of language acquisition in their students (children from 0 to 6 years old). The methodology consists of two consecutive phases: (1) the observation of child language abilities, to facilitate the evaluation of language acquisition level performed by a language therapist, and (2) the same language therapist evaluates the reliability of the observed results. A key result obtained from this evaluation was the identification of 7 out of 146 children with possible language delays that were previously undetected by either the NSLT or his/her educator. These cases require a formal diagnosis process to compare the system's decision with traditional methods.

B. Future IoToy framework

The term "Internet of Toys" appeared as a particular application domain of "Internet of things". Therefore, the commonly accepted definition is not complete. To be technically correct, we must extend the basic IoToys definition as: "Internet of Toys refers to a future where toys connected to the internet, not only relate one-on-one to children and other toys in complex learning/entertaining settings/environments (LESE), but all LESEs are wirelessly connected to other LESEs through cloud architecture".

In this section we define a new architecture as a general framework for future IoToys solutions (Fig. 3). This architecture allows all available state-of-the-art third generation LESE to be connected in one common Internet of Things solution. The cloud is a central element in this framework, acting as a hub for all subjects of this system. Data from all LESEs flow to the cloud, which is responsible to extract complex knowledge and share it with LESEs, so they all can benefit from participation in this system.

More formal presentation of the framework is given in Fig. 4. Most constituents of the framework are mapped from the IoT architecture, however there are entities exclusive for IoToys. The key difference is the active involvement of people at various levels in the framework, which makes this architecture remarkable compared to other application specific IoT architectures which are fully machine based. This framework is hierarchical, meaning that data cannot be sent directly from the toys as sensing units to the cloud, but through gateways or hubs. The main reason is energy efficiency, since the toys usually operate using low energy protocols such as Bluetooth, and rarely use GSM of Wi-Fi communication. Each LESE has to posses at least one hub able to communicate with the toys and with the cloud at the same time. The reverse process goes the same way, from the cloud to hub, and from the hub to the toys.

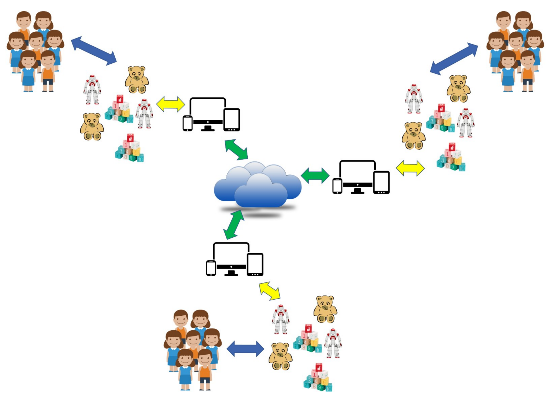

Figure 3. Future IoToys Framework.

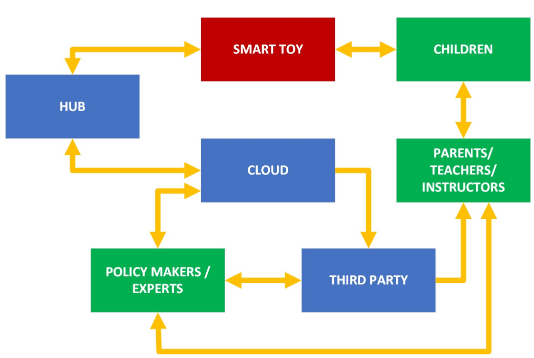

Figure 4. IoToys Framework architecture. Each rectangular represents an entity involved in the framework, with green ones referring to people. Yellow arrows depict data flows.

The general knowledge can be beneficial not only for the children, but also for the society at all, for policy makers and experts involved in children education, as well as for the business society interested to develop new toys, new applications for existing toys, or even new services for existing applications.

Specific knowledge about children includes identifying their abilities, talents, requirements, needs and wishes. This information can be of interest for the parents, since they can be instructed how to adopt to their kid' changes in behavior, interests, maturity, etc. For more important relations and more complex issues, they can be instructed to consider visiting professionals, teachers, or psychologist.

IV. Designing Challenges

In the following subsections challenges identified in the literature are discussed and analyzed in context of the proposed framework. The main challenges can be divided into two main classes, regarding their background.

A. Technical challenges

In the first class, the main challenges are similar with the challenges associated with other IoT based solution.

Interactivity in IoToys can be considered an umbrella term for many features that need to be implemented/provided in the framework all of which involve some type of interaction. The first aspect is providing the means for end users i.e. children to interact with the smart toy. This interaction should be done in the most natural way possible, ideally by only using sounds, facial expressions, gestures, and movement. This interactivity aspect can be accomplished through integrating different sensors, like microphone, camera, touch sensor, accelerometer etc., in the smart toy. One of the key differences between the IoToys and IoT is the response to the sensed data. While IoT predominantly works in a passive sensing mode, proactiveness is very important in IoToys. This defines the second interactivity aspect in IoToys, namely the ability of the smart toy to provide a feedback interaction with the child. This concept of active sensing combines the artificial intelligence of the toy with its data to guide the play scenario, further engage the child and make the overall experience more natural by creating an artificial personality of the toy. To provide this the smart toy needs a database and AI technologies on top of its operational hardware. In the proposed framework this potential problem can be relaxed by transferring smart toy data and AI to the hub. The final aspect of interactivity involves toy to toy interaction which can be accomplished physically but even more so virtually. The end goal of such interaction would be the interaction of the children using the toys. The proposed cloud centric framework can easily provide this functionality by pairing toys (children) either automatically using some expert system or by direct supervision of a human expert. Not all IoToys necessarily possess this third aspect of interactivity.

Toys interoperability is considered as the most important requirement that must be fulfilled for the toys to be able to "speak to each other". It is a common language that the devices can understood so they can be visible to each other. Currently, the available protocols for smart objects are not mature enough for communicate with other devices operating under the same protocols with different version. The situation is even worse if two devices operating under different protocols need to communicate. The only communication protocols that has achieved full interoperability with itself is Insteon with Z-Wave behind, and Zig-Bee being the worst [4][15].

Data security and data privacy issues in IoToys currently arise mainly due to the massive volume of children information gathered by the smart toys. Users give their consent to data collection and sharing because of the decrease of quality of user experience that is imposed if this is opted out. While there are ways to increase the data protection, e.g. routing any data transfer from the smart toys through the hub and define security policies there, there really need to be laws/policies regulating the legality of data toys harvest, process, and monetize. In the IoT applications, where connected devices are ready to be accessed from anywhere, the security issues should not be nullified [16]. Security of smart devices is heightened through device vulnerabilities (risk of threats which causes some loss of value to devices). IoToys is inherently vulnerable to common attacks of wireless networks. Security lightweight crypto-primitives can possibly provide a security policy at a low cost, by enabling authenticity of entities in the framework, integrity in the data flow and confidentiality of data by making it unreadable to others. Today's development of smart labels, memory amplifiers, and smart dust seems to mirror the sudden technology shifts, opening new forms of social interactions that change one's expectation of privacy or secrecy.

Big data issues are inherited by the process of managing and processing huge volumes of data by the central servers or clouds. The traditional databases fail to provide real-time processing of massive data streams that arrive from everywhere [17]. Therefore, new concepts appeared to overcome these issues, like non-relational database, new tools, techniques, and machine learning algorithm. Some solutions to this issue reshape the mainstream IoT framework, where the traditional centralized approach has been shifted toward load distribution, where all entities in the system can share the processing load. At the lowest level, the smart toys equipped with simple microcontrollers can perform some initial computation, known as dew computing [18]. At the next levels, entities responsible for transmitting data can also participate in data processing, performing more complex data processing tasks, known as fog (edge) computing [19][20]. At the highest level the cloud is responsible to provide very complex computation and to extract new knowledge from the available data. The data flow outlines the transition from raw data measurements, through information to knowledge, the highest level of understanding.

B. Non-technical challenges

EU General Data Protection Regulation requires the consent of a data subject (an individual, kid or parent) for a third party to legitimately process his/her personal data. This implies that the citizens must have a clear understanding about the way his/her personal data will be used by the system, which is hardly achievable in pervasive and ubiquity IoT context [21].

Ethical implications are related with managing clinical data or sensitive data about psychological development of children who are participating [22].

Business opportunities for designing advanced IoToys based services are endless (new platforms, tools, and applications), especially in big countries [23].

V. CONCLUSIONS

Internet of Toys research is still in the beginning, as only few groups in EU consider this topic, mainly from education perspective. In this paper we aim to overcome the gaps in the literature regarding this paradigm. Firstly, we provided a comprehensive definition of "Internet of Toys" with respect to sociological and technological perspectives. Secondly, we identified three generation of toys available on the market and proposed new IoToys frameworks/architectures that will be used as a solid base for interconnection of smart toys that are still not utilizing their full collective potential as IoToys. Lastly, we identified all relevant challenges associated with developing IoToys solutions. This overview should provide a comprehensive roadmap for parties that aim to employ this paradigm for business, industrial, educational or research proposes.

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