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Your Very Own Polar Bear: Drawing Attention to Household Energy Efficiency Through Gamification

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***Abstract*—This research article presents a virtual HomeMascot intervention, based on gamified AI and IoT technologies, to motivate the reduction of household energy consumption. HomeMascot, an endearing polar bear figure, motivates households to use energy in a sustainable way. Results of the study indicate that user-oriented, personalized real-time feedback on household energy and water consumption can increase awareness of sustainable living, and especially affects children's consumption behavior. The article describes the development, implementation, and measurement of effects of the intervention. HomeMascot has the potential to promote energy awareness in private households and the technical insights presented in the study serve as a blueprint for future energy usage monitoring systems designed to inform and activate users.**

***Index Terms*—Smart homes, IoT, Energy conservation, Gamification, Virtual assistants**

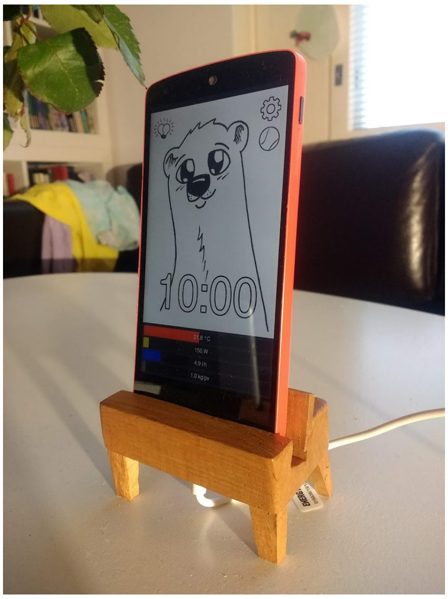

Fig. 1. The HomeMascot in action.

I. Introduction

The imperative to address the challenges of climate change is increasingly pressing. The EU's strategy for a sustainable future is grounded in the adoption of renewable energy and environmentally friendly industrial practices [1]. However, simultaneously, this strategy needs to be complemented by a fundamental shift in the consumption patterns and living habits of private households [2].

Unfortunately, the melting of ice caps and the distant plight of arctic polar bears often fails to resonate in our daily lives as usual framing of sustainability does not leverage personal relationships and responsibilities [3]. The HomeMascot intervention proposed in this study bridges this gap by personifying energy conservation efforts through the simulated feelings of a virtual polar bear (Figure 1). Its welfare is directly linked to the household's energy consumption patterns. The proposed approach integrates gamification, Artificial Intelligence (AI), Internet of Things (IoT), and smart sensor technologies to create an energy-saving intervention. The solution renders the abstract tangible and fosters a sense of personal responsibility towards energy-efficient living.

In this study, the intervention was deployed and evaluated across ten private households to study its flexibility, capabilities, and efficacy. Through surveys and interviews, HomeMascot was shown to promote sustainable living through the engagement of the entire family. The intervention made the users to consider their daily water, heating, electricity and artificial light usage patterns. The background for the study, description of the technical solutions, and the conduction of pre- and post-intervention surveys are provided, together with an analysis and interpretation of their results.

II. Background and Related Work

The European Union's ambitious climate goals highlight the necessity for a societal shift towards renewable energy and a reduction in consumption habits [4]. Also, the EU funding has been significantly increased in research and development of green technologies, signaling a strong commitment to achieving these climate goals.

Household direct energy use constitutes about one quarter of the net EU energy consumption [5]. Moreover, this consumption is 'doubly invisible' to consumers, obscured by its abstract nature and routine habits [6]. Gamification has proven effective in motivating behavior changes across various domains [7], and when combined with AI and IoT, it can create personalized, engaging systems that promote more energy-efficient behaviors [8]–[10]. For a more comprehensive discussion on related work, refer to these three reviews.

Despite these prior advancements, in 2023 Paneru and Tarigan emphasized the need for integrating smart energy apps with IoT technologies, such as home automation systems, to fully realize their potential for behavior change [11]. They highlighted the need to explore how feedback from these apps influences behavior, as studies have shown that mere energy usage displays in kWh have limited effects on promoting energy savings [12].

Therefore, a virtual character-driven gamification solution is proposed in this study. Developed within the framework of the Gamified Energy and Circular Economy Solutions ERDF project (https://uwasa.fi/peek), HomeMascot monitors and promotes sustainable living habits among private households and leverages rule-based AI to react to user behavior, thereby encouraging users to reduce their energy consumption. This approach not only aligns with the EU's climate goals but also addresses the broader challenge of integrating AI technologies into practical applications targeting energy conservation.

Hargreaves et al. [13] identify challenges in boosting household energy awareness, emphasizing whole-household engagement, acknowledging feelings towards energy displays, and diverse engagement across genders and ages. HomeMascot's novel interface addresses these issues by providing an accessible, relatable, and engaging way to monitor energy use, fostering a broad appeal and encouraging environmental responsibility.

III. Description of the Technical Details

The core of the proposed approach revolves around HomeMascot, a virtual polar bear mascot, which serves as both a guide and motivator for households to adopt more energy-efficient behaviors. This section outlines the different aspects of the development and deployment of the system:

- System Architecture: The system leverages the insights and feedback from the Gamified Energy and Circular Economy Solutions project to create a system that collects real-time energy consumption data via IoT devices and smart sensors.
- Gamification Mechanics: The intervention is structured around gamified elements of the HomeMascot Android application. The game mechanics are designed to engage users in energy-saving actions. If the users manage to keep the measured household energy and water consumption within the predefined limits, the application gives positive feedback and rewards the users with minigames.
- User Engagement and Data Collection: User energy consumption patterns, as well as their interactions with HomeMascot, can be recorded, monitored, and analyzed. Data from IoT devices and smart sensors provide a comprehensive overview of each household's energy use.

The HomeMascot is realized through a system that consists of an Android application, IoT sensor devices, a wireless local area network (WLAN) or wireless Access Point (AP), and a backend system (see Figure 2), which acts as persistent data storage for the collected data. The sensor devices monitor the environmental conditions and energy and water use of a household and the Android application communicates with the backend server through HTTP/POST requests.

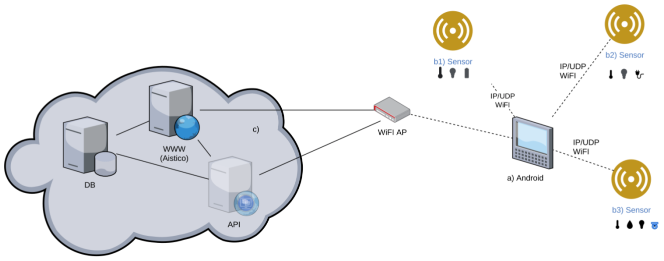

Fig. 2. The system architecture.

A. *HomeMascot Android Application*

The visible part of the system, the HomeMascot Android application, has four main views and it implements following main features:

- Configuration of the communication settings and sensors.
- Interfaces for setting family size, consumption thresholds, and interpreting sensor data.
- Consolidating and caching the data from artificial light use, room temperature, energy use, water use, and door/window sensors.
- Expressive feedback through the mascot's mood and reactions when predefined thresholds for the temperature, electricity, or water usage are exceeded.
- Providing rewards for users through playful interaction after periods of sustainable living.
- Scheduled or manual data transmission to the server.

Flexibility was a paramount consideration in the platform choice, leading to the selection of the Godot game engine due to its multi-platform support and open-source nature. Godot is a good choice when targeting lower-end hardware such as obsolete and outdated Android smartphones. Its broad platform compatibility and open-source nature also facilitate easy integration to diverse home automation and IoT device ecosystems.

The AI method chosen to implement HomeMascot character behavior emphasizes flexibility. Finite State Machines (FSMs) are a tried-and-true method to implement a game AI [14], [15, p. 32], especially since the pragmatic requirements did not necessitate the use of machine learning in this application. FSMs offer a robust and expressive mechanism to manage character behavior, which is encoded as states and transitions between them. The mascot's mood states and transitions are illustrated in Figure 3.

The mascot's expression changes in sync with the AI model state when any of the measured or average consumption values exceeds predefined thresholds. This allows managing the mascot's expressions even if multiple thresholds are exceeded simultaneously or when user actions influence the mascot's state. The FSM is initiated in a *fine* state and updates at a frequency of four times per second check for user interactions or high consumption values. Each type of threshold breach has a distinct visual expression of concern, grouped under a *troubled* state, including states like *hot, cold, sleepy,* and *drowning.* If multiple concerns are active simultaneously, the

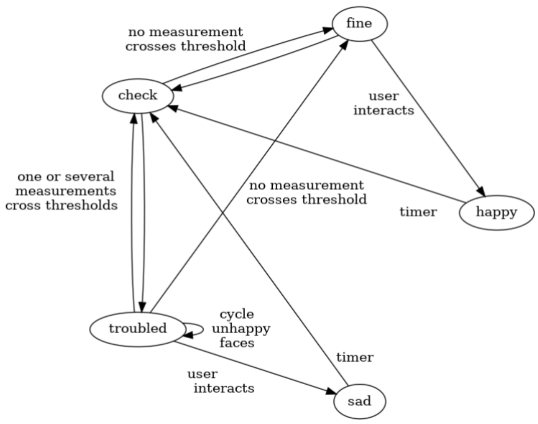

Fig. 3. The bear mood AI model.

state machine cycles through these expressions based on a timer. User interaction with the application also affects the mascot's state; if all measurements are within thresholds, the mascot briefly brightens up upon being petted, while concerns change its expression to a temporary sad one before returning to its base state or showing concerned expressions.

Another component that is central to the application is the datastore. It captures and caches the data on the smartphone and manages mascot application settings. The measurements from the IoT devices are categorized by type and sensor name, supporting data management for further analysis. The FSM checks the current consumption level from the data model, and in such is an important piece in providing dynamic feedback to encourage energy-saving behaviors. Consequently, the user is naturally guided to keep the bear character happy.

In tracking the consumption, the HomeMascot application utilizes an Exponential Moving Average (EMA) to provide a stable measure of household energy and water consumption over time. The EMA calculation weights recent sensor data more significantly than older data, allowing the application to respond to changes in usage patterns without overreacting to transient spikes from activities such as flushing toilets or boiling water with an electric kettle for a cup of tea.

The formula for EMA at a given time t is:

$$EMA_t = EMA_{t-1} + z_n(\nu - \mu) + z_{n-1}(1-\nu), \text{ where}$$
$$\alpha = \frac{t_n - t_{n-1}}{t - t_{n-1}}, \ \mu = e^{-\alpha}, \text{ and } \nu = \frac{1-\mu}{\alpha},$$

Here z_n and z_{n-1} denote the latest and the preceding measurements, respectively. Of the coefficients, μ functions as the foundational decay parameter that tempers the influence of time on data relevancy, and ν ensures the model's sensitivity to novel inputs. This approach is needed for the HomeMascot's data, which is typically characterized by irregular sampling intervals and consumption spikes. EMA provides a user-friendly tracking of energy consumption patterns. Note, that accuracy was not as important as it is to the energy companies. In HomeMascot, the users are interested in the variation of the *level* of consumption, not absolute real-time readings.

B. IoT Devices

Sensor devices were needed to evaluate the concept in real-world settings. A goal was set out to measure light and temperature, as well as enable reading existing water and electricity meters. An additional requirement was that sensors could be retrofitted non-invasively.

Initial exploration of Android phone sensors revealed their scarcity in mainstream devices. Additionally, the proprietary and costly nature of commercial solutions, which restrict data access, prompted the development of custom sensor devices. These devices utilize the open-source ESP8266 microcontroller, chosen for its affordability and integrated Wi-Fi capabilities.

Three types of sensor devices were developed for HomeMascot intervention: 1) Room devices based on the ESP-01S module, with sensors capable of measuring temperature, light, and optional connectivity for toilet flush or door/window switches. 2) Metering devices based on the ESP-12E module, that can measure light levels and have sensor heads for toilet flush, electricity and water meters. 3) ESP-WROOM2 devices for battery-powered operation, with sensors for measuring temperature and light levels. The actual sensors were BMP280 (I2C), BH1750FVI (I2C), TCRT5000 and FC-51. The solution was cost-effective and allowed the data acquisition in the HomeMascot intervention study.

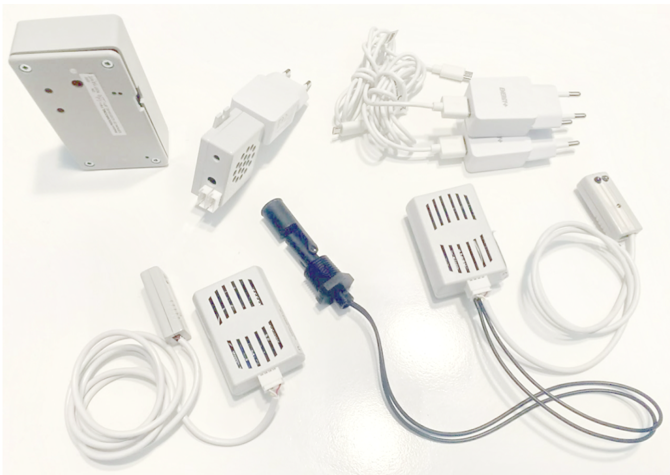

Fig. 4. A set of sensor devices with their sensor heads.

These devices were built in universal enclosures, with sensor headers for door/window/toilet flush, and water and electricity meter pulse sensors. These could be attached to the microcontroller with wired JST XH-4P connectors. A set of five sensors for a single household is shown in Figure 4.

The embedded firmware for these sensors was based on the ESP8266 core library [16]. The firmware manages sensor initialization, deep sleep and wake cycles, and data transmission to the Android application in the local wireless network. This ensured that the devices could connect to Wi-Fi networks, operate in low power modes, and perform and transmit periodic sensor readings.

IV. The Intervention and its Effect

Volunteer households for the HomeMascot intervention were sourced through an online form distributed via email lists, social media, and other communication channels. The call for participation was also promoted through videos showcasing the HomeMascot concept, presentations at events attended by the project team during the preparation phase.

From October to December 2020, HomeMascot underwent testing in ten private households located in the South Ostrobothnia region of Finland. Winter season made it possible to measure the effect of intervention towards heating and temperature adjustments.

The households ranged from multi-generational dwellings and tech-savvy single-occupancy apartments to older multi-resident homes and modern family houses. Among these households, three were single-person households, while the remaining seven were families with children (with the number of children ranging from one to four). Each intervention lasted approximately two weeks.

To prioritize the evaluation of the concept over usability refinements, the research team installed and configured sensor devices and HomeMascot application for the households. This approach also facilitated informal interviews and observations about the adoption, attitudes, and constraints of the solution. Those were then collected into field notes, which also provide the initial qualitative data for this empirical part.

To evaluate the effectiveness of the intervention, pre- and post-intervention surveys were designed. The surveys measured household expectations and experiences. For the sustainability aspects, metrics were established to monitor patterns related to the water consumption, electricity usage, and use of artificial lighting.

A. Pre-Intervention Survey

The pre-intervention survey encompassed a comprehensive description of various aspects, including household demographics, energy consumption patterns, attitudes towards sustainability, and technological preferences. The survey was conducted with all households ($n = 10$) before the installation of HomeMascot system. Test participants were asked about their living arrangements, habits, and their subjective assessment of water and electricity consumption, as well as their attitudes toward artificial lighting use. Additionally, it was inquired whether they already used any smart home applications and if they typically played mobile games.

Among the test households, five resided in detached houses, two in semi-detached houses, and three in apartment complexes. Six of these households relied on district heating as their primary heating source, while three utilized direct electric heating, and one employed an air heat pump.

Based on the survey results from the test households, 30% households were already equipped with smart home applications, primarily focused on lighting control. When asked about electricity use, 60% of test households estimated that their current consumption was lower compared to the average household. However, concerning water usage, 20% households estimated their consumption to exceed the norm. A noteworthy consensus emerged among almost all households, with 90% emphasizing the importance of switching off lights in unoccupied rooms. Similarly, 70% of the test households deemed adjusting indoor temperatures crucial not only for comfort but also as a means of economizing and conserving energy. Furthermore, games were familiar to the test households with 90% of them engaging in mobile gaming activities either on a daily or weekly basis.

Households expressed a high interest in leveraging HomeMascot to enhance their energy management skills, with a particular desire for guidance on energy-saving practices. For instance, test households anticipated the ability to monitor their electricity usage in real-time and looked forward to benchmarking their consumption against other HomeMascot users. It was considered that such features would serve as a catalyst for fostering greater energy efficiency and heightened awareness regarding electricity consumption patterns. However, one respondent raised concerns regarding potential information security issues in such features.

B. System Installation Observations

Technical challenges had been anticipated in installing the sensors, and so, the first households were selected based on their technological proficiency or prior strong interest towards the HomeMascot concept.

TABLE I
Summary of HomeMascot installations, their coverage, and the operation of sensors.

ID	Heat	Lights	Electricity	Water	Flush
0	B[3]	A	A	B	A
1	B	B	C[1]	D	-
2	B[3]	A	A	D[2]	A
3	C[4]	B[4]	-	C[1,4]	-
4	B[4]	B[4]	B[4]	-	-
5	B[3]	A	-	-	C[1]
6	B[1]	A	A	-	-
7	A[4]	A[4]	B[2,4]	D	-
8	A	A	D	-	-
9	A	A	B[4]	-	A
10	A	A	-	A	C[1]

Markings: A = No problems in installation or data collection. B = Installed and collected a significant amount data. C = Installed, but only little data was collected. D = Installation failed. - = Installation was not possible.

The sensor installation configuration was varied to adapt them to different types of living environments according to the test households, where calibration challenges and changes in the positive behavior expressed by the sensors were observed. The variations and challenges in data collection are summarized in Table I.

The first installations revealed a spectrum of technical and operational challenges. The attempt to monitor water consumption encountered obstacles due to [1]accidentally detached sensor heads, [2]infrastructural constraints or electrocution risks making the installation impossible and limiting the data collection in some settings. Furthermore, there were problems with [3]sensor calibration difficulties and inconsistent battery life of wireless sensor units. However, the ability to capture electricity usage data was consistently successful across the households, save [4]some issues with the phone software or in wireless connectivity, which provided valuable insights into energy consumption patterns.

Informal feedback from participants indicated a range of interactions with the HomeMascot system, from positive changes in response to energy consumption feedback to technical difficulties that hindered full engagement with the system. The variation in device compatibility, particularly among older Android devices, underscored the importance of ensuring broad technological accessibility and flexibility.

C. Post-Intervention Survey

The post-intervention survey comprised a detailed assessment of changes in energy consumption behaviors, feedback on the effectiveness of interventions, the perceptions of technological usability, and suggestions for future enhancements.

In many households, the application used an older backup smartphone. Regarding feedback concerning sensor operation, 40% of households reported encountering at least some issues with sensor functionality. Additionally, difficulties pertaining to the compatibility of certain types of water meters were identified as another operational hurdle.

Feedback regarding the HomeMascot polar bear character was overwhelmingly positive, with 90% households expressing satisfaction. Furthermore, seven out of nine considered the user interface to user-friendly, with its mini games providing enjoyable experiences. For those households encountering challenges, issues primarily revolved around wireless connectivity and data transmission difficulties. Such technical difficulties could make the intervention fail altogether: in one household, the enthusiasm of the children notably declined when the system failed to fully function during the initial testing phase.

In terms of impact, the utilization of HomeMascot was perceived by the households' subjective estimate to have led to a reduction in electricity consumption in 60% of the households. Furthermore, 70% households reported paying more attention to needless artificial light use. Only 20% households adjusted their heating to a cooler setting based on the recommendations from HomeMascot.

In two households where mostly the children used HomeMascot, the final feedback indicated that the family's electricity consumption had decreased, and more attention was paid to turning off unnecessary lights. Conversely, in two households where mostly the adults used HomeMascot, adjustments were made to lower room temperatures. In three households with mostly one adult user, no changes in consumption habits were reported. Cross tabulation suggests that HomeMascot had the largest consumption behavior change in family units with kids.

Water consumption monitoring had the most technical difficulties. Therefore, unsurprisingly, 60% reported that HomeMascot had no noticeable effect on their household water usage while 20% indicated a reduction in water consumption attributable to HomeMascot. Notably, 90% reported a more positive attitude towards monitoring both electricity and water consumption after getting to know HomeMascot.

In their final feedback, households expressed a desire for HomeMascot to provide statistics over extended periods, incorporate goal-oriented weekly or daily tasks, offer immediate feedback on choices made, and introduce more engaging features and educative minigames.

Overall, user feedback gathered in the surveys provided valuable insights for enhancing the system, including the addition of more interactive features to strengthen users' emotional connection with HomeMascot.

V. Conclusion and Discussion

The results show that gamification, especially when combined with AI and IoT technologies, can influence household energy consumption behaviors. This finding aligns with existing literature [8]–[10] that underscores the potential of gamification as a powerful tool to engage and motivate individuals towards achieving desired behaviors.

Feedback from study participants indicated a heightened awareness of energy consumption patterns and a more proactive approach to implementing energy-saving measures. Furthermore, the user experience seemed to be overwhelmingly positive: Surveys and interviews with participants revealed a high level of engagement and satisfaction with the HomeMascot platform. The interactive nature of the AI controlled mascot and the gamification mechanics were praised for their role in motivating participants, but especially children, to adopt more energy-efficient behaviors and habits.

The experiences in deploying the solution have been meticulously documented. This forms a critical foundation for refining the technical considerations and deployment of such home monitoring and automation systems. The results also highlight the essential balance between user engagement and technical robustness in designing effective energy use monitoring tools. The use of Exponential Moving Average used by the HomeMascot to provide a stable and smoothed measure of household energy and water consumption over time, was well received. Favorable evaluation of such approach is one of the main takeaways from the study.

The survey responses enabled a qualitative analysis of user experience, engagement and perceived shifts in energy consumption behaviors. While estimating the effectivity of the intervention remains subjective, as there was no pre-intervention energy consumption data, many households reported behavioral changes which validate HomeMascot's potential as an effective tool for promoting energy conservation.

The study illustrates how a low-cost solution can be built to enable non-invasively retrofitted energy monitoring of private households. However, the deployment of such interventions remains to present a challenge: while the results are promising, expanding the program to a broader audience would require careful consideration of technological, logistical, and ethical aspects. Addressing challenges related to scalability, access, ease-of-installation, and long-term impact will be crucial for maximizing the benefits of such interventions.

Considerations for long-term data storage and application scalability were out of scope in this study. Still, issues such as data access, data privacy, user consent, and the digital divide could potentially arise, and limit the access to and effectiveness of such programs across different demographics. Therefore, the commercial adaptation of the concept would require additional device, software, and business model innovations that would require the coordination of multiple stakeholders.

Overall, the intervention's success in reducing self-reported energy consumption in many of the participating households emphasizes the crucial role of personalized feedback. Adding an AI-driven customization to the goals could ensure that each participant receives relevant and achievable challenges, increasing the likelihood of sustained engagement and behavior modification. Such personalized approach, powered by real-time data analysis, would set a new standard for interventions aimed at energy efficiency. The observations support the conclusion that future smart home energy solutions would benefit from incorporating similar AI and IoT elements that were proposed in the HomeMascot intervention.

The long-term impact of gamified interventions remains an area for further research. While short-term reductions in energy consumption were observed, it is unclear whether these changes persist over time without continuous engagement through the gamification platform. Future studies could explore ways to sustain motivation and commitment to energy-saving behaviors beyond the intervention period.

Future research could focus on refining the data analysis tools and capabilities of HomeMascot to allow deeper insights into household energy consumption patterns. Furthermore, the recent AI technology advances would allow digital voice and natural language-based interaction with edge devices such as the HomeMascot phone [17]. Exploring how personalized and personified feedback and interactive interfaces could influence energy-saving behaviors would be a promising research topic.

In conclusion, the "Your Very Own Polar Bear" HomeMascot intervention demonstrates intriguing case study in combining IoT technologies to gather data, AI to control virtual character behavior, and gamification to promote energy efficiency in private households. In doing so, the study contributes to broader efforts to mitigate the effects of climate change.

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