A Smart Home Energy Management System Using IoT and Big Data Analytics Approach

SEMINAR REPORT

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This is to certify that the seminar entitled

A Smart Home Energy Management System Using IoT and Big Data Analytics

Approach

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ABSTRACT

Increasing cost and demand of energy has led many organizations to find smart ways for monitoring, controlling and saving energy. A smart Energy Management System (EMS) can contribute towards cutting the costs while still meeting energy demand. The emerging technologies of Internet of Things (IoT) and Big Data can be utilized to better manage energy consumption in residential, commercial, and industrial sectors.

This report presents an Energy Management System (EMS) for smart homes. In this system, each home device is interfaced with a data acquisition module that is an IoT object with a unique IP address resulting in a large mesh wireless network of devices. The data acquisition System on Chip (SoC) module collects energy consumption data from each device of each smart home and transmits the data to a centralized server for further processing and analysis. This information from all residential areas accumulates in the utility's server as Big Data. The proposed EMS utilizes off-the-shelf Business Intelligence (BI) and Big Data analytics software packages to better manage energy consumption and to meet consumer demand.

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1 INTRODUCTION

Effective management of Energy consumption in smart homes saves money, enhances sustainability and reduces carbon footprint at large. However, the lack of low cost, easy to deploy, and low maintenance technology has somewhat limited a large-scale deployment of such systems.

The sheer quantity of data collected throughout different cities of a country presents multiple challenges in data storage, organization, and analysis. Internet of Things (IoT) technology and Big Data are natural candidates to address these challenges. IoT technologies can provide a ubiquitous computing platform to sense, monitor and control the household appliances energy consumption on a large scale. This data is collected using many different wireless sensors installed in residential units. Similarly, Big Data technology can be utilized to collect and analyze large amounts of data [1]. Data analytics on this data using business intelligence (BI) platform [2] plays an essential role in energy management decisions for homeowners and the utility alike. The data can be monitored, collected and analyzed using predictive analysis and advanced methods to actionable information in the form of reports, graphs and charts. Thus, this analyzed data in real-time can aid home owners, utilities and utility eco-systems providers to gain significant insights on energy consumption of smart homes. The energy service providers can use the power consumption data available with analytics engine to provide flexible and on-demand supply with appropriate energy marketing strategies. The consumers, being aware of their consumption behavior and having a close interaction with the electricity utilities, can adjust and optimize their power consumption and reduce their electricity bills.

Finally, as an additional advantage, the use of IoT also enables seamless remote access control of home devices where the customers get online access to the ON/OFF usage pattern of in home appliances via a personal computer or a mobile phone.

Rest of the report is organized as follows. Previous work in using Home Energy management System (HEMS) is presented next. This is followed by the proposed system requirements. The system architecture is presented next followed by a description of implementation details. Evaluation and testing is described and succeeded by the conclusion.

2 RELATED WORK

2.1 Home Energy Management System (HEMS) using a ZigBee Module

In [3, 4, 5], an implementation of a HEMS Unit in a Wireless Sensor Network using a ZigBee Module to communicate with sensor nodes, is presented. The system monitors the device consumption data and sends control signals to end nodes during peak load hours. However, the lifetime of a WSN network deteriorates with time due to the deployment of new sensors in the network. Additionally, Han et al. in [6] introduced a system for monitoring power consumption using ZigBee as the communication protocol in a WSN. However, in this system the data was collected and aggregated solely by the home server which could lead to data loss in case of a system failure. Moreover, a bridge between ZigBee and TCP/IP stack would be required to connect this system to a community of homes.

2.2 Extending the Previous Work

In [7, 8], the above mentioned WSN networks have been extended to wider ranges in the IoT paradigm utilizing the GSM/GPRS networks to remotely control the end-devices.

2.3 An Integrated Cloud-based Smart Home Management System

In this paper [12], a hierarchical, smart-home service architecture employed with multiple in-home displays for user interfaces is described by them. In this research, a home controller system interfaced with device sensors is responsible for aggregated energy reporting of all devices to home owners. For community representatives, a community broker server is integrated with different home network devices such as security cameras within a community. Furthermore, a comparative analysis between Message Queuing Telemetry Transport Protocol (MQTT) and Hypertext Transfer Protocol (HTTP) is also performed to determine which protocol was more efficient in providing home control services [12]. The design of the proposed architecture, however, lacks the incorporation of Big Data which is instrumental in processing and analyzing huge volume of data collected from several home sensor networks.

2.4 Developments of the in-home Display Systems for Residential Energy Monitoring

Multiple in-home display systems (IHDs) and automatic meter reading systems (AMR) were discussed in the context of providing energy management information in [14]. Depending on the ambient conditions, the smart home systems could choose the display devices such as TV, smartphone or tablet computers and accordingly select the appropriate user interface. The architecture, however, lacked a standardized user interface for all the home devices that could accomplish the requirement for multiple displays.

2.5 Home energy management system based on power line communication

This architecture of HEMS utilizing power line communication was addressed in [15]. Using smart meter data, this HEMS can monitor and provide real-time information on home energy consumption along with online access to devices status, thus allowing remote control of devices by customers. The proposed design is based on standard HTTP protocol and does not provide support for lighter-weight communication protocol like MQTT which is essential to scale up the system in order to accommodate multiple residential areas.

3 PROPOSED SYSTEM REQUIREMENTS

The functional requirements of the system are specified as general functional requirements and specific system requirements. The general requirements are the system's functionality and specific requirements are different business processes delivered. Non-functional requirements comprise of system's attributes such as scalability, security, privacy.

The proposed system's functional requirements are:

- The SoC should gather power consumption information and the ambient condition information periodically, and send it to a centralized server.
- The server should parse the information and transmit the readings to a central data storage system or database.
- The stored data should be used by analytics engine to process it and generate reports, graphs, and charts.
- Clients should be able to view the generated graphs through a cross-platform mobile application.
- Depending on the user privileges, the application should render different services to each user such as viewing reports, device status, and remote control of device or bill payment.

The proposed system's non-functional requirements are:

- Scalability

  The data is collected and analyzed on a national level accommodating four different levels of stakeholders: Home Owner, Community Representative, State Representative and Country Representative. Each stakeholder has its respective view of the data and services offered. The six business processes mentioned above should be applied to each stakeholder as required. To serve these levels of clients, the system should be based on an easily scalable architecture.

- Security

  Security of the system is important as a minor flaw in system design can lead to catastrophic disasters. Multiple levels of security such as secured web service calls using https must be implemented to ensure protected communication of the system.

- Privacy

  The communication between server and end devices should be private. Access control using two factor authentication and proper encryption techniques should be utilized to prevent illegitimate users from prying over the data.

4 SYSTEM ARCHITECTURE

Based on the above system requirements, the proposed system's hardware and software architecture are as follows:

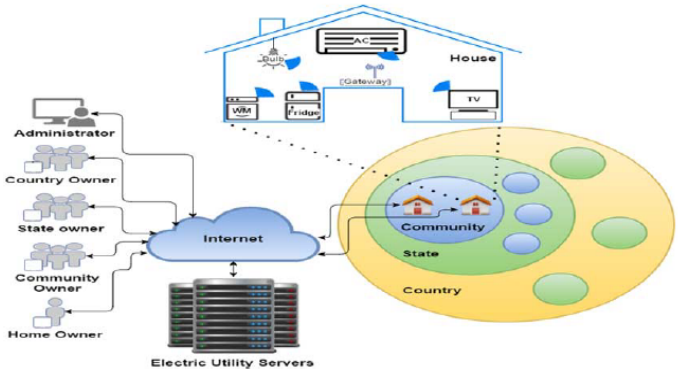

Figure 1. Systerm Architecture

4.1 Hardware Architecture

4.1.1 Sensors and Actuators

As the proposed system is to monitor and control the AC units, an integrated temperature and humidity sensor is interfaced with the microcontroller to measure the ambient conditions. In addition, a solid state relay is controlled by the microcontroller to switch ON/OFF the devices accordingly. A current sensor is used to measure the AC current to calculate the power consumption.

4.1.2 High-end Microcontroller

A SoC high end microcontroller is used as edge device data acquisition module that manages the HVAC unit. The compact sized, high speed and lightweight SoC is suitable for residential areas. Table I displays the specifications of the micro-controller used in this study.

4.1.3 Servers

In the proposed architecture, the servers are high-end PCs which can also be deployed on Cloud for wide-scale accessibility. The installed servers are: MQTT Broker, highly scalable Storage Server, Analytics Engine server, and a Web server. The functionality of each server developed and utilized will be explained in the software architecture section.

Component	Description
Digital Ports	18 I/O ports
Analog Ports	8 ADC and 2 DAC
Memory	1MB Flash, 128 kB RAM

Table 1. MICRO-CONTROLLER SPECIFICATION

4.2 Research Materials

A writing task and a survey questionnaire were developed to evaluate whether learners benefitted from the proposed system. The purpose of this study is to investigate learners' general performance in emotion word use. Thus, Ekman's six emotion categories was adopted, the most used characterization in many previous studies, while designing the writing task. For each category, we designed three individual scenarios, which were determined based on the results of a pilot study. The scenarios, described in the participants' first language to avoid misunderstandings, were to illustrate the emotion category instead of suggesting a specific emotion word. Table 1 exemplifies scenarios for anger and disgust. The participants were allowed to decide their own events relevant to the given scenarios. Also, they were to express a consistent emotion through the whole writing in at least 120 words and use a specific emotion word to describe their feelings.

In addition, a seven-item reflection questionnaire was developed to elicit participant opinions on RESOLVE. The first two questions sought information on participant writing behaviour and demands for tool support. The next four questions explored participant views on the system's experiences in terms of system usability, the quality and number of suggested emotion synonyms, and usage information. The last question elicited participant perceptions on context-aware emotion vocabulary learning. All the questions used the five-point Likert agreement scale ranging from 1 (strongly disagree) to 5 (strongly agree).

4.3 Data Collection Procedure

A pilot test was conducted three months before the experiment to identify the feasibility and effectiveness of the operational procedure. A group of 19 EFL college students enrolled in an English writing course participated in a five-week experiment involving the RESOLVE system. We thereafter revised the experimental design based on these preliminary results. The study

was conducted outside of class time and lasted for five weeks:

Pre-test: At the beginning of the study, the participants took an English proficiency test. Afterwards, they were evenly divided into six groups according to their proficiency test scores. Then the six categories were randomly assigned to the six groups. All the participants completed a writing task based on the second scenario of the assigned emotion categories.

Treatment: During the three-week treatment phase, each participant was required to complete a total of nine writings for three scenarios of the assigned emotion category on the RESOLVE system. Precisely, three writings for one assigned scenario had to be completed per week. The participants were allowed to decide the events relevant to the given scenarios. After reviewing the synonymous emotion words and the corresponding usage information, the learner could either select one of the suggested emotion words or keep his original one to describe his feeling. Note that in order to maintain the quality of learning, the interval between any two writings from the same participant was at least 24 hours.

Post-test: In the post-test, all the participants were to complete another writing task on the second scenario of their assigned emotion categories. They also filled in the survey questionnaire.

Several issues are worth noting. First, the second scenario was determined to avoid the effect of short-term memory mainly because the writing task of scenario two was per- formed in the third week, which was not too close to either the pre-test week or the post-test week. Second, the events they described in the pre- and post-tests were identical. The purpose was to compare the appropriateness of the emotion words the participants produced. Third, the participants were unable to refer back to their previous writings, which discouraged them from copying the previous writings. Note that on both the pre- and post-tests, the participants completed their writings using the RESOLVE interface but with the suggestion of synonymous emotion words withheld.

4.4 Design of Scoring Criteria

To evaluate the appropriateness of learners' emotion word use, a 7-point grading scale ranging from 0 (the least appropriate) to 6 (the most appropriate) was used. Two native- speaker judges,

trained before the pilot study, were given the participants' pre-and post-writings as well as the lists of synonyms of the target emotion words they produced, which were extracted from the corpus. The judges gave scores to each emotion synonym on the lists based on the participants' contexts. Note that the judges had no information about the target emotion words participants produced in both the pre-and post-writings, which avoided scoring bias. Participants' word choice rather than grammatical accuracy was the focus in the evaluation. If two or more words were considered equally appropriate, they were given equal scores. A weighted Cohen's Kappa value of 0.68 indicated substantial agreement between the judges.

5 RESULTS AND DISCUSSION

The current study investigates whether and to what extent RESOLVE helped language learners with emotion word use. We examined learner emotion word use in the pre- and post-writings as well as analysed their reflections of RESOLVE experience. To reflect learner performance accurately, the results of the two judges' evaluations on each issue were reported respectively.

5.1 Tool Effectiveness on Learner Use of Emotion Words

The first research question investigated whether learners benefitted from the proposed tool support. To answer this question, we compared learners' scores of their emotion word use in the pre-and post-writings. Besides the gain scores, we also reported learners' error reduction ratios (ERR) in order to avoid analytical bias.

$$ERR = \frac{Post - Pre}{Max - Pre} \tag{1}$$

The error reduction ratio (ERR) quantifies the learner's error reduction from the pre-test to the full mark, which is shown in above equation. where Max is the full mark (six in our scoring scheme), Post and Pre are the scores of post- and pre-tests, respectively. This can be interpreted as a measure of the room for improvement. Note that errors in this study indicate inappropriate emotion word use. Taking this study as an example, two learners both improved their scores by 1 point (out of 6): one learner's score increased from 4 to 5; the other from 5 to 6. Their improvements were 20.0

We first compared learners' average scores in the pre- and post-tests. The first row of Table 2 shows that all learners achieved expected gains. ANOVA results revealed that there was a significant difference between learner performance on the pre-test and post-tests (Judge 1: F(1,64)= 9.67, p value=0.003 and Judge 2: F (1,64)= 9.92, p value=0.002). This indicates that the participants made improvement on emotion word use after the three-week treatment.

	N	Judge 1			Judge 2		
		Pre-test	Improved score	Average ERR	Pre-test	Improved scored	Average ERR
All learners	33	3.18	1.70	0.58	3.64	1.84	0.87
Highly proficient	15	4.33	0.27	0.34	4.40	1.33	0.83
Less proficient	18	2.22	2.89	0.68	3.00	2.28	0.89

Full marks = 6.00

Table 2. Participant performance on pre-and post-tests

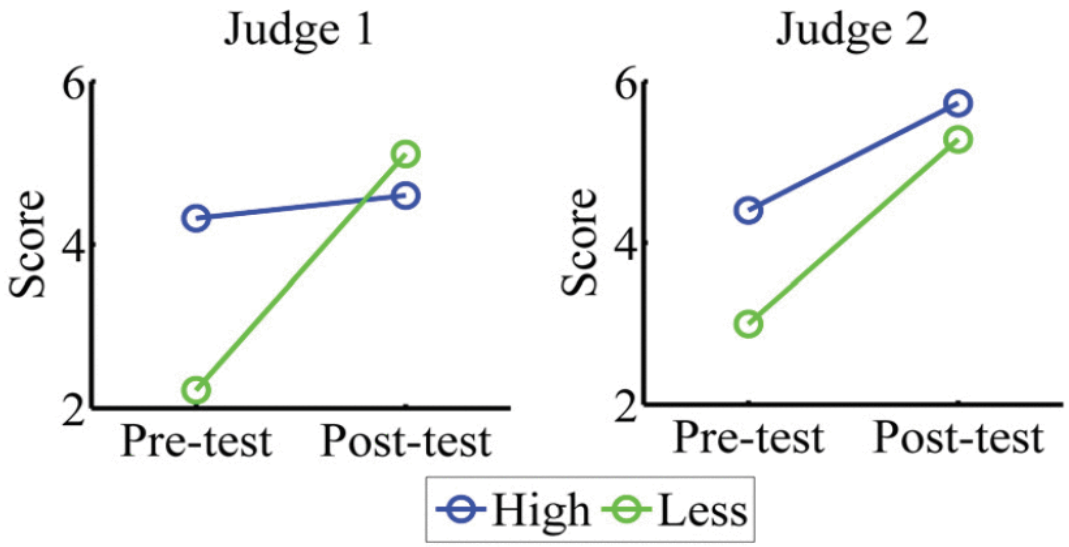

Figure 3. Learning effectiveness of students with different proficiency levels

Next, we investigated whether RESOLVE was of great benefit to different learners (Table 2, second panel). To do so, the participants were divided into two groups based on their scores of the proficiency test, which was conducted in the first week. A total of 15 participants scored above or equal to the grand average (67.45), so they were classified as highly proficient. The other 18 participants with below-average scores were classified as less proficient. The average scores of the highly and less proficient groups were 80.93 and 56.22 out of 100.00 respectively. The learning effectiveness of the highly and less proficient students is visualized in Figure 3. Both figures showed that after the treatment, less proficient students made more noticeable improvement as compared with the highly proficient students. In fact, less proficient students achieved almost the same or even higher levels of performance in the emotion wording task than their counterparts.

The significance of the improvements of both groups was further quantified by ANOVA: the first judge's evaluation showed a significant difference between both the highly and less

proficient learners (F(1, 31)=9.76, p value=0.004), whereas according to the second judge, no significant difference existed between the two groups (F(1, 31)=.71, p value=0.405). To understand whether less proficient learners benefited from the tool support, or highly proficient learners' higher scores in the pre-test limited their potential for improvements, we calculated learner error reductions. Clearly, the ERRs of the less proficient learners were higher than those of the highly proficient learners based on both judges' evaluations. It indicates that the less proficient learners made significant progress even after the error residual was normalized despite insignificant difference between the two groups in the second judge's view. Since the results revealed that the less proficient learners showed greater improvements, we further sought to investigate how the performance of these two groups differed, which is discussed in the next section.

5.2 Performance Comparison of Learners

The second research question attempted to explore how the improvements of highly and less proficient learners differed. A second order polynomial curve was used to fit these (proficiency level, improved score) data points: the trend is shown in Figure 4. From the first judge's evaluation (left subfigure), a negative relationship can be seen between the learners' language proficiency and their improved scores. In other words, the lower the proficiency level, the more improvement achieved by the participant. The second judge's view, however, was somewhat different. The right figure reveals a downward trend for highly proficient learners and a slightly upward trend for less proficient learners. This means that for the highly proficient group, the higher the proficiency level, the smaller the gain; however, the less proficient learners did not follow this pattern.

Taken together, the judges shared similar opinions with respect to the performance of the highly proficient learners whereas there were discrepancies for the less proficient learners. To investigate these differences, we scrutinized the individual performances of the less proficient participants. Discrepancies were found in four less proficient participants, so the data of these four participants were particularly examined. Table 3 shows the breakdown of the participants' emotion words and their scores in the pre- and post-tests.

Participant		Sentence with emotion word	Judge 1	Judge 2
#12	Pre-test	Even if I did not show displeasure, really a little taste and ***uncomfortable** when I found out that I was forgotten.	0	0
	Post-test	I really feel a little ***upset** when I found out that I was forgotten from my mom.	2	6
#25	Pre-test	However, two years later, they sent wedding invitations to all of us and said they date each other for four years! Wow! What a ***surprise**!	1	6
	Post-test	After two years, they were married! I was so ***surprised**!	4	6
#23	Pre-test	Be straight to say: those bad smokers really ***pissed me off** with their action and attitude.	1	0
	Post-test	That's why I always have unpleasant and ***sickening** feeling of those bad smokers.	5	0
#28	Pre-test	I felt so ***happy** that I can travel with my best friends and we will have more trips in the future!	1	6
	Post-test	We had a great time and wonderful memory so this trip did bring me ***joy**.	6	6

Note. Full marks = 6.00.

Table 3. Breakdown of four participants' emotion word use and scores before and after treatment

Specifically, from the perspective of Judge 1, these four participants showed improvements whereas from Judge 2's view, no one made progress except Participant 1. Although both judges agreed on Participant 1's improvement, they were not consistent about the appropriateness of his emotion word use. We then take a further look at the performance of the other three participants from the evaluation of Judge 2. Participant 2 and Participant 4 received full marks in the pre- and post-tests, leaving no room for improvement. Turning to Participant 3, the zero point in both pre- and post-tests showed that his emotion words were the least appropriate. For this reason, the views of both judges differed greatly. Researchers such as Dewaele and Pavlenko suggest that the use of emotion words is related to individual experience; this could explain the judges' divergent views.

If we exclude the markedly different data, a similar trend can be seen in the judge evaluations as that seen in Figure 5. That is, for the less proficient group, the lower the proficiency level, the greater the improvement. In contrast, for highly proficient participants, the higher the proficiency level, the smaller their gains. This could be because they had confidence in their command of emotion words, as evidenced by the fact that seven out of 15 participants used the same emotion words in their pre- and post-writings, which scored full marks. On the other hand, 16 out of 18 participants used different emotion words in their writings. Their improved scores showed that their attempts were successful.

It is worth noting that for the participants whose English proficiency was extremely high or extremely low, the bene- fit of RESOLVE was less obvious. It is not surprising that advanced learners had sufficient competence to make appropriate lexical choices. On the other hand, the low-achieving learners' limited vocabulary was likely to make emotion word learning much more demanding. Overall, less proficient learners significantly benefitted from the proposed system, RESOLVE, in emotion word learning compared with the highly proficient learners, which was expected.

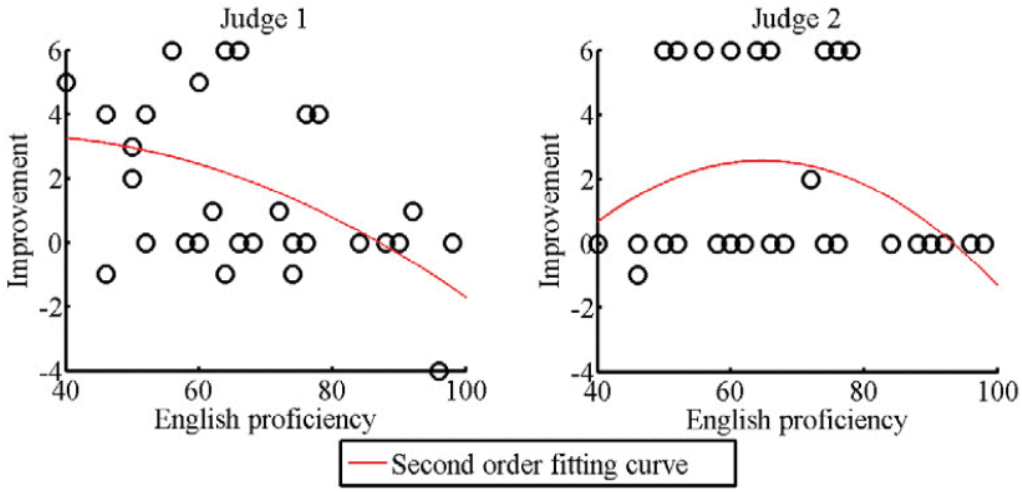

Figure 4. Relationship between learner language proficiency and extent of improvement

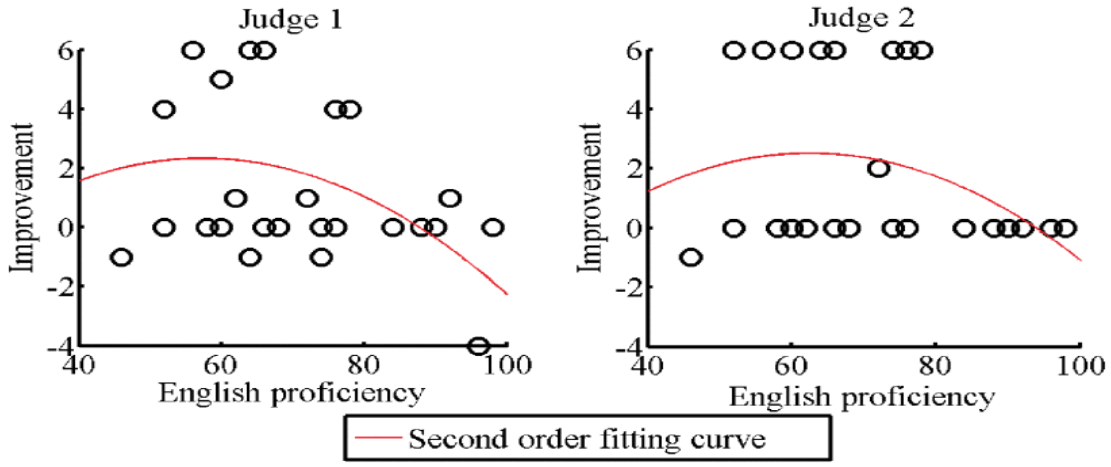

Figure 5. Relationship between learner language proficiency and extent of improvement excluding the four outliers

5.3 Learners' Perceptions of Context-Based Emotion Synonym Learning

To answer this research question, a seven-item reflection questionnaire was designed to elicit participant perceptions on RESOLVE in terms of learner needs, system usefulness, and its contribution to language learning. Moreover, participants' open-ended responses were collected to elicit the rea- sons underlying their answers to each closed-form question. To have a greater understanding of the opinions of different students, the feedback of learners with different proficiency levels was analysed (Table 4). A two-sample t test was carried out, and the results showed no significant difference between the two groups' responses. Learners' perceptions on each survey question were discussed below.

The first panel illustrates the participant learning back- grounds: their writing behaviour (item 1) and their needs for tool support (item 2). The scores of these two items were quite high (all above 3.80/5.00). Both groups reported that they intended to restate their feelings. To have a better under- standing of the behaviour of the two groups, we scrutinized the emotion words produced by the participants and found that eight highly and 16 less proficient participants used different emotion words in their pre- and post-writings. It is likely that highly proficient participants had greater confidence in their emotion word use than the less proficient ones. Meanwhile, participants' strong demand for tool support indicated that learners needed help to be engaged in emotion word learning.

The second panel shows participant perceptions on system usefulness, including system function (item 3) and suggested information (item 4-6). First, the tool usability scored quite high. In particular, both groups were satisfied with being able to consult synonyms and usage information directly without switching visual focus between webpages while composing their writing. The results supported previous research on the split-attention effect: Learning in an integrated environment reduces mental effort and improves learning results. Participants' feedback showed that our design met their needs. Second, the information provided by RESOLVE included the ranked emotion words (item 4), the number of synonymous emotion words (item 5), and the usage information (item 6). Both groups appreciated the suggested emotion words as well as the usage information. Less proficient learners particularly acknowledged that the usage information (i.e., scenario descriptions, definitions and example sentences), benefit them in learning to use emotion synonyms appropriate to their contexts. Interestingly, both groups did

not seem to share similar views on the number of suggested synonyms, even though there was no significant difference between them. Less proficient learners appreciated five suggestions whereas highly proficient participants expected more suggestions. Some participants suggested that eight synonyms would yield adequate choices for better wording.

The last question (item 7) sought participant reflections on the role of RESOLVE for language proficiency. Nearly 80% of the learners (26 out of 33 participants) saw RESOLVE as a practical reference aid that benefited their writing and promoted language competence. A significantly higher number of less proficient learners (n=16) acknowledged the tool assistance. The opinions of the less proficient participants echoed the findings of the previous research questions that they received greater benefit from the tool support than their counterparts.

	Item no.	Item	ALL (33)	Highly (15)	Less (18)	*t* (*p* value)
			Mean (SD)	Mean (SD)	Mean (SD)	
Learner needs	1	An attempt to use synonyms to restate their emotions	3.91 (1.04)	3.80 (1.08)	4.00 (1.03)	-0.543 (0.295)
	2	A demand for tool support	4.00 (0.97)	4.07 (0.80)	3.94 (1.11)	0.356 (0.362)
System usefulness	3	System functions	3.97 (0.88)	4.00 (0.85)	3.94 (0.94)	0.177 (0.430)
	4	Suggested emotion words	3.79 (0.86)	3.80 (0.68)	3.78 (1.00)	0.073 (0.471)
	5	Number of emotion words	3.61 (1.09)	3.27 (1.22)	3.89 (0.90)	-1.682 (0.051)
	6	Usage information	3.79 (0.78)	3.73 (0.80)	3.83 (0.79)	-0.361 (0.362)
Language learning	7	Can help achieve better language proficiency	3.88 (0.74)	3.80 (0.86)	3.94 (0.64)	-.0552 (0.292)

Note. Out of a total of 5.0. *p <.05.

Table 4. Survey results of participant perceptions on RESOLVE

6 LIMITATIONS AND FUTURE WORK

To the best of our knowledge, this is the first study considering the application of sentiment analysis to assisting language learning. It is worth mentioning that although the focus of the current study is emotion vocabulary learning, the RESOLVE system can be easily adapted for other vocabulary or synonym learning. While the preliminary findings supported that the developed system was beneficial to emotion word use, there are limitations in this study that could be improved. For example, a greater number of participants should be involved, which could help us take a closer look at potential learner difficulties in the use of emotion words. Also, tool comparison (e.g., online thesauri) could be conducted to examine their individual impacts on learners.

7 CONCLUSION

Emotion vocabulary has been an important concern in several disciplines. They were especially widely used in sentiment detection or prediction. However, it has not received particular attention in foreign language teaching and learning. In view of the paucity of research, we developed RESOLVE, a context-based emotion synonym suggestion system. Developed using machine learning techniques, RESOLVE is capable of suggesting contextually appropriate emotion synonyms. The usage information is also provided to reinforce learner's word use. The tool effective- ness was assessed using a writing task and a reflection questionnaire. The results demonstrated that both the suggested emotion synonyms and the corresponding usage information are beneficial to learners' use of emotion vocabulary. Notably, less proficient participants showed greater improvements.

Mastering emotion words is a challenging task for language learners, so emotion vocabulary should be explicitly taught and consciously learned. The RESOLVE system is applicable for use in classroom teaching and activities. The approach proposed in this study could be replicated in the classroom. Instructors could create various scenarios for specific emotion categories and have their students compose writings via consulting RESOLVE. Afterwards, instructors elaborate on how the words students produce could be used in various scenarios. Such pedagogical activities enable learners to develop a clearer understanding of as well as stronger command of emotion word use.

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