Viewer Perception of Superellipsoid-based Accelerometer Visualization Techniques

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Abstract— *Viewer perceptions of superellipsoid-based glyphs representing trend analysis of tri-axial accelerometer data are studied in this paper. A trend analysis and its mapping to the superellipsoid parameters is proposed. Detailed results from a viewer survey about the usefulness of such glyphs are presented. Survey results indicate that approximately 60% of the respondents correctly identified the trend-related information and as much as an additional 27.2% acceptably identified some of the trend-related information. Overall, respondents indicated that the superellipsoid-based glyphs were helpful to understand accelerometer multi-plots.*

I. Introduction

Tri-axial accelerometers are increasingly being used in sensor networks for a variety of purposes including human activity recognition and detection of position and velocity changes of human motions, see for example [1]–[3]. Typical visualizations of accelerometer data are shown as time independent multi-plots, one plot per axis, similar to Figure 1. While these plots provide details of changes in each of the axes over time, the viewer must often analytically process those details. This is especially true when additional correlated information are included in the multi-plots. Understanding trends in the accelerometer data may be facilitated by alternatively representing the accelerometer data as special three dimensional glyph objects in a visualization, perhaps combined with the accelerometer multi-plots.

Glyphs in general have been well investigated in the literature (e.g. [4]). Superellipsoid-based glyphs for visualization purposes have also been investigated [5]–[8]. In the latter two, shape identification and specific pre-attentive order of superellipsoid parameters are discussed. For the most part, these studies have concentrated on general usability issues. We have not noticed any specific study aimed at representing trend analysis of tri-axial accelerometer data. Interpreting accelerometer-based multi-plots may often require technical knowledge about the system, application or environment. Viewers are likely to have previous experience in interpreting waveform and multi-plot graphs. Our interest is to combine visualization techniques that facilitate pre-attentive processing with the typical accelerometer multi-plots. Specifically, to provide the accelerometer multi-plots as semantic zoom operations from superellipsoid-based glyphs. Our objective is to facilitate easier and quicker understanding of the trends inherent in the accelerometer data. The focus of this paper is to study via a viewer survey superellipsoid-based visualization techniques of tri-axial accelerometer data.

Our work is different from previously reported work in that we emphasize superellipsoid visualization aspects of trends in the accelerometer data. This allows us to concentrate on using shape-related attributes to heighten the pre-attentive interpretation of the correlated data.

The rest of this paper is organized as follows. The accelerometer trend analysis model is described in Section II. The survey together with its results are discussed in Section III. Conclusions are presented in Section IV.

II. Visualization Model

Superquadrics including superellipsoids were first proposed by Barr in 1981 [9]. The parametric equation for a superellipsoid is given in Equation 1. Here, a_1, a_2, and a_3 are the lengths of the superellipsoid along the x, y and z axis respectively; ϵ_1 and ϵ_2 are form facts that determine the shape of the superellipsoid.

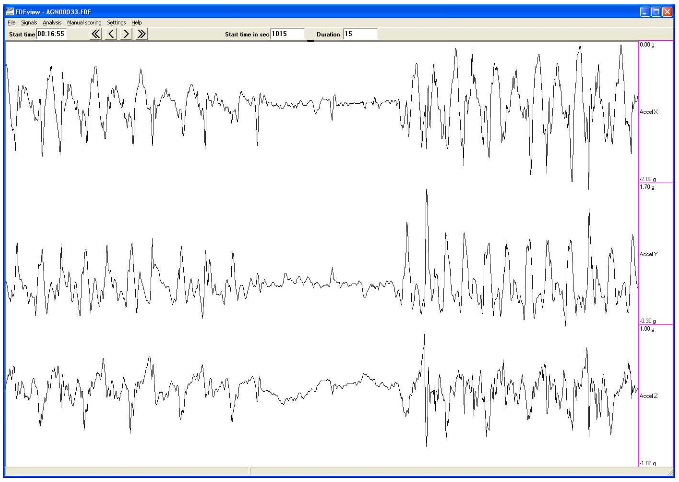

Fig. 1. A typical tri-axial accelerometer multi-plot showing 15 seconds of data, 75 samples per second (data set courtesy of Prof. Jun Jo, Griffith University, Australia)

$$\mathbf{r}(\eta, \omega) = \begin{bmatrix} a_1 \cos^{\epsilon_1} \eta \cos^{\epsilon_2} \omega \\ a_2 \cos^{\epsilon_1} \eta \sin^{\epsilon_2} \omega \\ a_3 \sin^{\epsilon_1} \eta \end{bmatrix} \tag{1}$$

where $-\pi/2 \leq \eta \leq \pi/2$ and $-\pi \leq \omega < \pi$.

We map the accelerometer axes values to the respective superellipsoid axial lengths (size) parameters. For several reasons including data smoothing and data downsizing, we compute the average from a forward time averaging window, denoted by $W_s : [t_i, t_i + \Delta_s]$ for the time frame from t_i for Δ_s time units. The case $\Delta_s = 1$ time unit reduces to individual input values. These averages are mapped to the visual primitive parameters as follows. We map the magnitudes of the average acceleration values to the size parameters offsetting by a parameter α: Equation 2 (equations for y and z are similar). We do not consider the acceleration direction information in this paper.

$$a_1 \leftarrow \alpha + \left| \frac{\sum_i ax_i}{n} \right| \mid ax_i \in W_s \tag{2}$$

A forward time averaging window is used in which to calculate behaviors. However, a different window is used so as to provide flexibility for longer pattern detection if needed. Let $W_b : [t_i, t_i + \Delta_b]$ denote the behavior window, and as before, for the time frame from t_i for Δ_b time units. In this paper, the standard deviation σ is used to estimate the dispersion of the acceleration values from the mean of the values in W_b, small variations are deemed smooth behaviors whereas large variations are deemed violent behaviors. We compute the total deviation as the summation of the deviations for each of the axial values. This positive real number scalar represents the combined behavior of the multi-plot.

The standard deviation is mapped to ϵ_1 and ϵ_2 in the following way. First, σ is normalized on the interval $[0, 1]$ by determining the minimum and maximum deviations of the window and scaling the minimum to zero and the maximum to one. Second, this normalized standard deviation is subsequently scaled to the selected interval of the form factors, that is on $[0.1, 4.0]$ as follows: σ for the interval $[0, 0.5)$ scales to $[0.1, 1)$, $[0.5, 0.5]$ scales to $[1.0, 1.0]$ and $(0.5, 1]$ scales to $(1.0, 4.0]$. This has the effect that middle dispersion of data, i.e., moderate behaviors, are represented by elliptical shapes (spherical if the size factors all equal to one), that smooth behaviors are represented by rectangular shapes (cubical if the size factors are all equal to one), and violent behaviors are represented by pinched star-shapes. Both form factors are assigned the same value as determined by this procedure, thereby, providing perceptively easier shape cues to distinguish the behavior patterns. The ordered superellipsoids were displayed in the survey, see Figure 8.

III. SURVEY

The purpose of the survey is to determine how useful our proposed visualization model is in facilitating the understanding of accelerometer data and trends. The survey consisted of four parts (see Table I) and required approximately 15–20 minutes to complete. All parts were answered on a seven page questionnaire form. However, parts II through IV required interactive online manipulation of three dimensional superellipsoid objects.

There were 29 survey respondents. Table II lists the general demographic information of the respondents.

A special online survey application was implemented in AVS/Express that provided three graphical output windows labeled **A**, **B** and **C**, and

TABLE I
SURVEY STRUCTURE

Part	Description
I	Demographic
II	Qualitative axial length (size) difference between two superellipsoid objects
III	Qualitative behavior categorization based on superellipsoid shape
IV	Comparison of superellipsoid and tri-axial accelerometer multi-plot representation

TABLE II
SURVEY DEMOGRAPHICS

Description	Percentage breakdown
Profession	82.8% Engineering, Computer Engineering or Computer Science 10.3% Social Science, Psychology, Humanities, Languages or other similar 6.9% did not report (but are believed to be engineering related)
Gender	69% male 31% female
Ethnic[a]	majority were East Asian and South Asian together with a small number of Caucasians.
Education[b]	48.3% master's, 44.8% four year degree or bachelor's.
Age	41.4% 18–25 years 55.2% 26–32 years
health [c] & ability[d]	93.1% healthy and capable 6.9% did not report (but are believed to also be healthy and capable).
Prior experience[e]	51.7% did not take such a course 41.4% did take such a course 6.9% did not report.

[a]Ethnic information was not requested on the survey
[b]highest level of education
[c]eye condition
[d]generally sufficiently experienced in using a computer
[e]Computer visualization, graphics, art design or drawing course in the past three years

the Survey Control Panel. The three-dimensional superellipsoid objects were displayed in Windows **A** and **B** along with the x, y and z axis orientation. A two-dimensional graph was displayed in window **C**. Some of the output windows were de-activated during parts of this survey. The user could rotate the superellipsoid objects in each window via a left-mouse drag operation. The user was given sufficient time in which to manipulate the objects prior to the start of the survey. Color was not a factor in these experiments. Superellipsoid objects were displayed

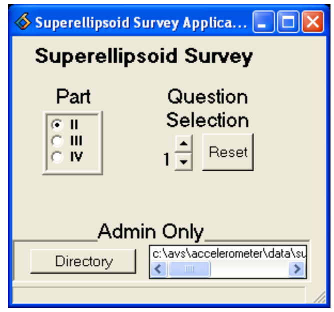

Fig. 2. Survey Control Panel, user and administrative sections.

with two types of coloring, first, a latitude coloring facilitated the identification of the z-axis, second, a red-with-blue-spot color simulated the proposed base coloring of our model (coloring is left for future information display purposes). The survey control panel consisted of two parts; the upper portion was displayed to the user. Figure 2 shows the survey command panel. Subsequent figures also show the user-portion of this panel.

Part II surveyed the user perception of the relative qualitative axial lengths (sizes) between two separate objects. This part consisted of a total nine questions with varied object sizes and shapes. Care was taken in the preparation of the visual presentation to ensure that: a) the same scale between the two objects (windows) was used, b) that the object size was not automatically scaled during a resizing of the window itself, and c) that the object resize button available from the 'master' AVS/Express window was not visible to the user. However, nevertheless, we noticed the rare case where the size of the object in one or both windows changed relative to the other. In these cases, we reset the survey to address this issue. We therefore feel that the error introduced due to this issue is small or negligible. Figure 3 illustrates the visual presentation that was provided as part of the example for Part II and Figure 4 shows the worked-out survey question accompanying this visual presentation. Figure 5 shows the visual presentation for the last question in this part.

Table III lists the superellipsoid parameters used as well as the specific axis length asked for in each question in this part. The question identification includes both the question number and the object window letter. The notations $>$ or $<$ refer to greater or less than whereas $>>$ and $<<$ refer to much

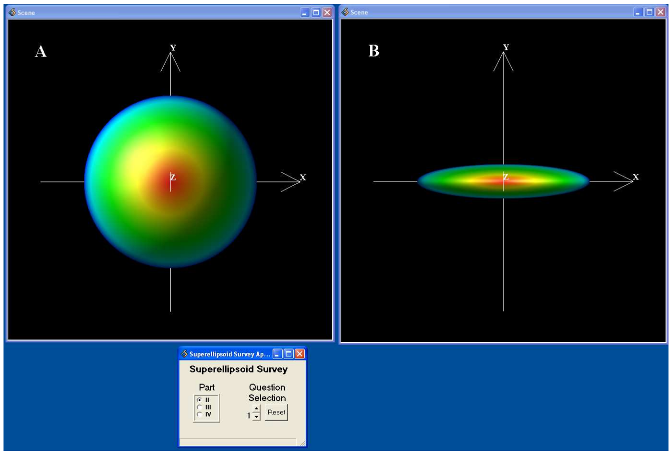

Fig. 3. Visual presentation of Part II survey questions, this image corresponds with the example survey question displayed in Figure 4.

1. (Example) The y size of Object A is ______ the y size of Object B.
   (1) much less than
   (2) less than
   (3) the same as
   (4) greater than
   (5) much greater than

Fig. 4. Part II example survey question, this survey question corresponds with the visual presentation shown in Figure 3.

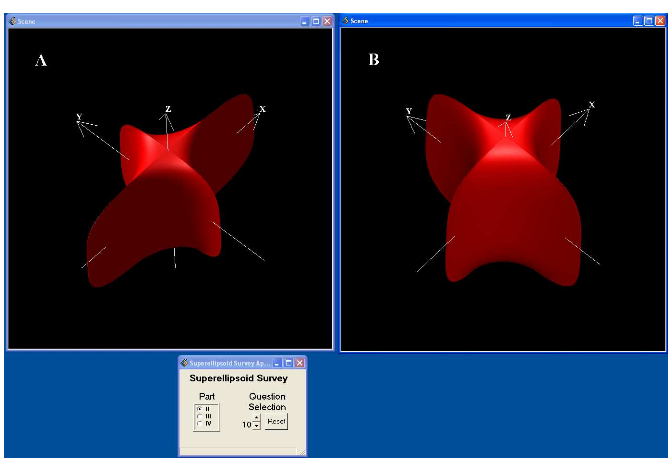

Fig. 5. Visual presentation of Part II survey questions, this image corresponds with the last question in this part.

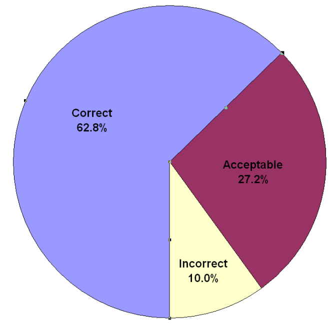

Fig. 6. Overall percentage breakdown of responses for Part II of the survey.

greater and much less than, respectively. Question 1 refers to the example and corresponds with Figure 3; Question 10 corresponds with Figure 5. The description column indicates the particular axis that was asked for comparison. The last column indicates the numeric difference of the indicated axis length and is derived from the corresponding subtraction of the a values.

Overall, Figure 6 shows the percentage breakdown of correctly, acceptably, and incorrectly identified qualitative determinations for the questions in this part. A response that was ‘next too’ the correct response is considered as acceptable, for example, in Question 1 (the example), the correct answer is much greater than, however, greater than would be acceptable. Allowing acceptable responses anticipates the subjectively inherent in such qualitative determinations.

Figure 7 details the response breakdown per question. In particular, Questions 2, 4, 8 and 10 had the clearest difference between correct and non-correct responses. On the figure, the black diamonds graph the last column of Table III. By inspection, there appears to be little correlation between the actual axial length (size) and the qualitative determination of this length. We suggest that the three axial lengths combined with the shape may lead to some degree of interference when trying to determine a specific length.

Lastly, we separately consider the responses of only the declared Engineering, Computer Engineering or Computer Science respondents. For this subset, the identifications improve slightly: 69.9% - Correct, 25.0% - Acceptable and 5.1% Incorrect. However, since our study does not provide us suffi-

TABLE III

SUPERELLIPSOID PARAMETERS USED IN PART II

Question	color	a_1	a_2	a_3	ϵ_1	ϵ_2	Description	Comparison	Diff.
1A	latitude	1	1	1	1	1	$y_1 >> y_2$, (example)	y	0.8
1B	latitude	1	0.2	1	1	1			
2A	latitude	1	1	1	1	1	same	x	0.0
2B	latitude	1	1	1	1	1			
3A	latitude	0.8	0.6	1	1	2	$x_1 << x_2$	x	0.6
3B	latitude	1.4	0.6	1	1	2			
4A	latitude	1	1	0.1	0.1	0.1	$z_1 << z_2$	z	0.7
4B	latitude	1	1	0.8	0.1	0.1			
5A	latitude	1.4	0.6	1	4	3	$x_1 >> x_2, y_1 << y_2$	x	0.8
5B	latitude	0.6	1.4	1	3	4			
6A	red-blue	1.4	1	0.7	1	2	$y_1 < y_2$	y	0.2
6B	red-blue	1.4	1.2	0.7	1	2			
7A	red-blue	1.4	1.4	1.4	0.1	0.1	$y_1 > y_2$	x	0.0
7b	red-blue	1.4	1	1.4	4	4			
8a	red-blue	1.4	0.9	0.5	0.4	2	$x_1 >> x_2, y_1 < y_2, z_1 << z_2$	z	0.9
8b	red-blue	0.6	1.3	1.4	0.7	3			
9A	red-blue	1.2	1.1	1	2	2	same	y	0.0
9B	red-blue	1.2	1.1	1	2	2			
10	red-blue	1.4	0.8	0.8	0.5	4	$x_1 > x_2, y_1 < y_2, z_1 < z_2$	z	0.4
10	red-blue	1	1.2	1.2	0.5	4			

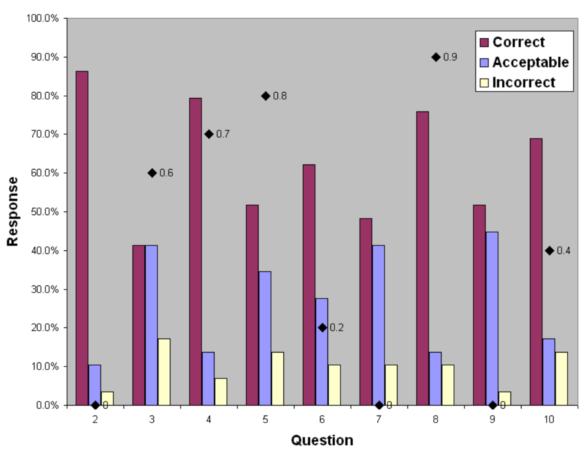

Fig. 7. Detailed percentage breakdown of responses for Part II of the survey, the black diamonds graph the last column of Table III

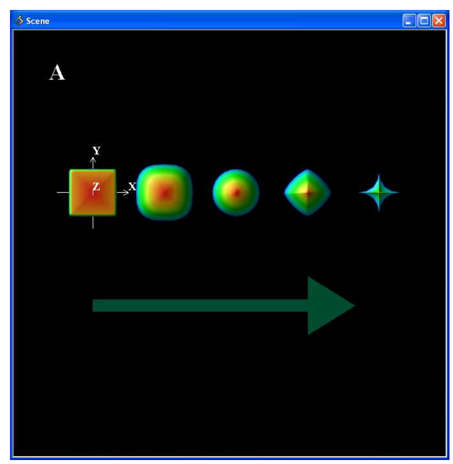

Fig. 8. Part III shape behavior scale, in order left-to-right, $\epsilon_1 = \epsilon_2$ =01, 0.7, 1.0, 1.5, and 4.0 corresponding to very mild, mild, moderate, violent and very violent, respectively; this image was displayed as the first question in this part.

cient sample diversity for non-engineering related backgrounds, we draw no conclusions from this data.

Part III surveyed user perception of the behavior categorization based on superellipsoid shape. The motivation stems from the hypothesis that smooth shapes suggest normalcy whereas very pointed shapes suggest the opposite. The first visual presentation in this part displayed the behavior scale consisting of five superellipsoid objects in increasing order as indicated by the arrow, see Figure 8. Although this scale was not shown nor provided as a reference during the remainder of the survey, a number of respondents were observed to 'flip' back to this question to review the behavior-shape order. This part consisted of a total of eight questions as shown in Figure 9.

Table IV lists the superellipsoid parameters used for each question in this part. The category column

2. Object A's shape suggest ______ behavior.
   (1) very mild
   (2) mild
   (3) moderate
   (4) violent
   (5) very violent

Fig. 9. Part III survey questions.

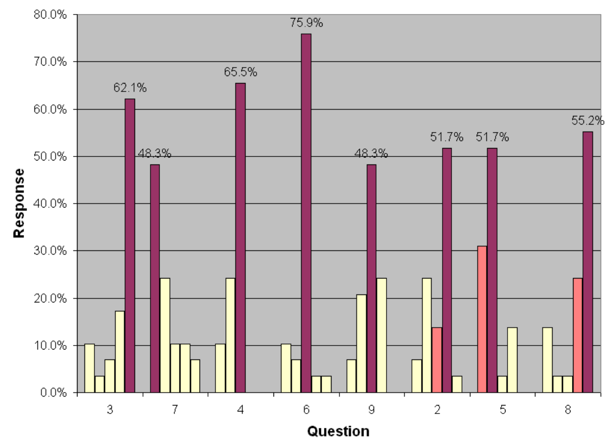

Fig. 10. Detailed percentage breakdown of responses for Part III of the survey, the order of the questions corresponds with that of Table IV.

indicates the category of the question and is described further below. The comparison column indicates the correct and if applicable, the acceptable responses. The last column indicates the numeric difference between the ϵ_1, ϵ_2 in the question and that of the closest figure in the five object behavior-shape scale (Figure 8).

The questions were organized into several overlapping groups. All questions except one had the same uniform superellipsoid size parameters. The five questions in the category 'same' used the same superellipsoid shape parameters as one of the objects in the behavior-shape scale. For these questions, only correct versus incorrect behavior identification is scored. Within these five, Questions 4 and 6 have the same shape (sphere) and differ only by color model; Question 9 varied the size parameters. The three questions in the category 'accept' used shape parameters in-between the objects in the behavior-shape scale. For these questions, the first identification in the Comparison column indicates the expected result and the second indicates an acceptable response. We present the survey results according to this breakdown.

Figure 10 details the responses for Part III of the survey. The order of the questions is as given in Table IV. Within each question, the five bars correspond with the possible answers in the order of the survey question shown in Figure 9. The correct responses for each question are shown in dark red (dark gray) along with the percentage of respondents choosing this answer. The average correct response for all questions is 57.3%. There is also a distinct difference between the correct answers and all the others (for the 'accept' category, this distinction is also noticeable although slightly less so than those in the other categories). The distribution of incorrect responses shows limited clustering about the correct response, as may be expected due to the inherent subjectivity in the judgments. These observations lead us to suggest that providing additional training and/or providing the behavior-shape scale as an on-demand available reference could lead to improved results. Interestingly, although the superellipsoids in Questions 4 and 6 had the same size and shape, the identification results and distribution of the results are somewhat different. This may be due to the color differences between the objects, or perhaps more likely, a lack of familiarity with the process or with the behavior-shape scale. If the latter, then additional training should improve the consistency in responses for these two questions. Lastly, the response for Question 9, although lower than the average, compares with some of the other responses. We suggest that axial size and shape may be sufficiently separable.

The last part of the survey compared the superellipsoid representations with the typical multi-plot visualization. All superellipsoids used in this part were generated from one second samples from the data set shown in Figure 1. Respondents were asked three questions about which axis had the largest/smallest average acceleration and three questions about the suggested behavior (using the same scale as before). For each of these six questions, respondents were also asked to rate the usefulness of the superellipsoid visualization on the scale of: very useful, little bit useful, about the same as, not

TABLE IV

SUPERELLIPSOID PARAMETERS USED IN PART III

Question	color	a_1	a_2	a_3	ϵ_1	ϵ_2	Category	Comparison	Diff.
3	latitude	1.2	1.2	1.2	4	4	same	very violent	0.0
7	red-blue	1.2	1.2	1.2	0.1	0.1	same	very mild	0.0
4	latitude	1.2	1.2	1.2	1	1	same	moderate	0.0
6	red-blue	1.2	1.2	1.2	1	1	same	moderate	0.0
9	red-blue	1.4	1	0.7	1	1	same	moderate	0.0
2	latitude	1.2	1.2	1.2	2	2	accept	violent, moderate	-0.5
5	latitude	1.2	1.2	1.2	0.4	0.4	accept	mild, very mild	±0.3
8	red-blue	1.2	1.2	1.2	3	3	accept	very violent, violent	+1.0

that useful and very un-useful. For space reasons, we only report the overall average response here: approximately, a little bit useful.

IV. CONCLUSION

Viewer perceptions of superellipsoid-based glyphs representing trend analysis of tri-axial accelerometer data are studied in this paper. The trend analysis and the development of the superellipsoid-based glyphs are presented. The main part of the paper details the survey questionnaire that was given to 29 volunteer participants as well as the interpretation of the survey results. Details about the survey are included in this paper, in part, so as to provide for scientific experiment comparison by other researchers interested in this area. The survey results are very positive. Survey results indicate that approximately 60% of the respondents correctly identified the trend-related information and as much as an additional 27.2% acceptably identified some of the trend-related information. Overall, respondents indicated that the superellipsoid-based glyphs were helpful to understand accelerometer multi-plots.

These results confirm our expectation regarding the potential deployment of superellipsoid-based glyphs, in particular, for representing tri-axial accelerometer data. Our on-going work focuses more on the application of visualization of correlated data from multi-sensors including multiple tri-axial accelerometers.

ACKNOWLEDGMENTS

We are grateful to Prof. Jun Jo, Griffith University, for providing to us the data sets used in this research. We also thank the individuals who volunteered their time to complete the surveys.

This research was supported by the MIC (Ministry of Information and Communication), Korea, Under the ITFSIP (IT Foreign Specialist Inviting Program) supervised by the IITA (Institute of Information Technology Advancement, C1012-0801-0003)

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