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Smart System on Two-dimensional Shapes Recognition Application for Kindergarten Students

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Abstract. Kindergarten-aged children are going through an important period of cognitive development, such as the ability to think concretely, including recognizing simple geometric shapes such as circles, triangles, and squares. However, many children find it difficult to understand the basic concepts of two-dimensional shapes.
Purpose: It is necessary to develop prototype learning aids in the form of intelligent systems in two-dimensional shapes applications for kindergarten students, which utilize information technology and object visualization directly through cameras on smartphones. This is expected to increase children's learning motivation and help strengthen their understanding of two-dimensional shapes.
Methods: The research combines Waterfall and Agile methodologies, tailoring them to four stages: plan and discovery, analysis and design, application development, and testing. Testing gathers accuracy with 120 smartphone-collected data points for square, triangle, circle, and pentagon shapes. Also, usability testing based on learnability, efficiency, memorability, error handling, and satisfaction, was obtained from six kindergarten teacher questionnaires and quantitatively processed.
Results: The application achieves an accuracy rate of approximately 79%. Notably, accuracy decreases with fewer corners, mainly due to low resolution or lack of focus, resulting in simplified detected shapes. Regarding usability, it is evident that the application has received positive feedback from users, particularly kindergarten teachers, who have given it an average score of 78.83.
Novelty: Distinguished from previous research, the novelty of this study resides in its ability to capture objects through a camera, eliminating the need for predefined shapes within the application, and innovating by creating an educational tool aligned with the kindergarten curriculum to recognize two-dimensional shapes. The research contribution is the creation of an innovative learning tool for kindergarteners, merging smartphone technology with real-world objects to teach two-dimensional shapes, thus integrating technology into early childhood education effectively, which has urgency in efforts to improve the quality of learning.

Keywords: Early childhood, Geometric objects, Artificial systems
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INTRODUCTION

At the beginning of the kindergarten phase, the child experiences an important in cognitive development [1]–[3]. At this stage, children begin to develop the ability to think concretely and recognize the concept of simple geometric shapes such as circles, triangles, and squares. They learn to compare different shapes and understand each shape's basic features, such as the number of sides and angles. Learning basic concepts of two-dimensional shapes in kindergarten children generally involves playing, drawing, and manipulating simple geometric objects. Teachers and parents play a role in providing direct experience to children through play and exploration of geometric shapes [4]. However, from observations, many cases show that the concept of two-dimensional shapes is still difficult for children to understand. They have difficulty distinguishing basic shapes such as triangles, squares, pentagons, and circles, thus requiring special guidance in understanding the concept. In addition, teachers and parents need to understand the stages of cognitive development of kindergarten students to choose the right learning method and provide clear guidance in understanding the concept of two-dimensional shapes.

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In addressing the challenges of teaching two-dimensional shapes to kindergarten students, teachers and parents are currently implementing various creative and interactive teaching strategies. They utilize teaching aids such as geometric blocks, puzzles, and drawing materials to help children understand the shapes and spatial orientation of objects in two-dimensional space. Educational games are designed to reinforce their understanding of basic shapes and concepts in two-dimensional geometry. Furthermore, parents engage children in everyday activities that involve recognizing and utilizing fundamental shapes in flat structures, such as constructing structures with blocks and cutting paper. Learning from the methods employed by teachers and parents to facilitate the introduction of two-dimensional shape concepts to kindergarten children, it is evident that engaging and captivating teaching methods are essential. Incorporating games, drawings, and visually oriented activities is crucial. In today's context, where kindergarten children are already interacting with smartphones, interactive learning facilitated by information technology holds particular appeal. Therefore, this research aims to develop a learning tool in the form of an intelligent system within an application for recognizing two-dimensional shapes, tailored for kindergarten students. Utilizing the smartphone's camera, objects are captured and transformed into corresponding two-dimensional shapes. This approach enables kindergarten students to easily and swiftly grasp fundamental concepts in geometry, including two-dimensional shapes, through an innovative and enjoyable method.

Academics have conducted research related to educational aids utilizing information technology through mobile devices or smartphones. Applications involving geometric shapes have been developed for junior high school students [5], for elementary school students [6] using both two-dimensional and three-dimensional shapes; using three-dimensional shapes for college students [7], [8], for junior high school students [9], for elementary school students [10], [11]; and using two-dimensional shapes for elementary school students [12]. All studies involving these geometric applications utilize predefined shapes provided within the application. However, in the case of kindergarten students, research diverges from geometric shapes to other objects, including letters [13], [14], numbers [15], human body parts [16], colors [17], and various objects [18]. Distinct from prior research, this study's innovation lies in capturing objects through a camera, thereby eliminating reliance on predefined shapes within the application. Furthermore, the novelty also lies in the development of an educational aid for recognizing two-dimensional shapes aligned with the kindergarten curriculum.

The research contribution introduces an innovative learning tool tailored for kindergarten students, utilizing smartphone technology to translate real-world objects into two-dimensional shapes, and it effectively integrates technology into early childhood education, addressing a crucial gap in educational aids while enhancing the understanding of geometric concepts at a foundational level. This research is urgently needed as it directly addresses the pervasive struggles faced by kindergarten children in comprehending fundamental geometric concepts. By swiftly developing an innovative learning tool employing smartphone camera technology, it aims to bridge this critical gap, laying the groundwork for an enhanced educational experience at the kindergarten level and igniting a strong motivation among children to grasp these essential concepts more effectively and enthusiastically.

METHODS

The research involves four steps or stages, adopting a methodology that combines the Waterfall and Agile software development methodologies [19]– [21], tailored to specific needs. Combining Agile and Waterfall methodologies creates a hybrid approach that harnesses the strengths of both methods. It typically begins with a structured planning phase similar to Waterfall, where project scope and initial requirements are defined. However, as the project progresses, Agile principles are integrated to introduce iterative development cycles, continuous testing, and feedback loops. In this hybrid model, the structured phases of Waterfall, such as planning, analysis, and design, are adapted to accommodate flexibility and iterations. Agile's incremental development approach allows for ongoing adjustments based on evolving requirements and stakeholder feedback. This means that while the project maintains a structured framework, it also incorporates Agile's adaptability and responsiveness to change. The integration of Agile principles within the Waterfall structure enables a more flexible and adaptive project management style. It encourages regular reviews, collaboration, and the ability to incorporate modifications throughout the development process [22]–[25].

This hybrid model aims to balance the benefits of structured planning and documentation with the agility to respond to changing project needs efficiently. It utilizes and merges into four phases: plan and discovery, analysis and design, application development, and testing and evaluation, as illustrated in Figure 1.

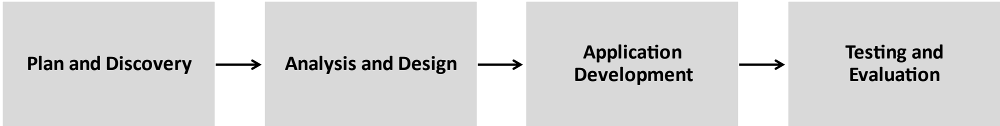

Figure 1. Stages of research

In the initial stage, which is the planning and discovery phase, activities involve observing and analyzing the needs within the kindergarten curriculum and cognitive learning processes, followed by a literature review and planning related to this research topic and its implementation. The outcomes of the analysis phase are presented using Data Flow Diagrams (DFD) [26], [27], while in the design phase, the results are depicted through flowcharts, incorporating the method of two-dimensional shape detection with the Harris Corner Detector algorithm [28]–[32]. Development of applications using the Kotlin programming language [33], [34] that produces an Android-based application. In the final stage, testing is conducted on the application to obtain accuracy values in flat shape recognition and usability scores from users.

The data for accuracy calculations are collected using an Android-based application installed on smartphones, totaling 120 data points, with 30 data points each for triangle, square, pentagon, and circle shapes. Additionally, usability scores are obtained through questionnaires filled out by six teachers at a kindergarten. The questionnaire is related to the use of the application with usability testing [35] consisting of five points, namely learnability, efficiency, memorability, error handling, and satisfaction. The questionnaire data is processed quantitatively by calculating the average results.

RESULTS AND DISCUSSIONS

The first-level DFD [36] modeling depicts the entire system. Figure 2 illustrates the Context DFD for the Smart System on Two-dimensional Shapes Recognition Application. It involves a single external-entity/sink/source, the User, which provides two data flows, two-dimensional shape data and testing input, into the system. From the system, two data flows, two-dimensional shapes formed and recognized, are provided to the User.

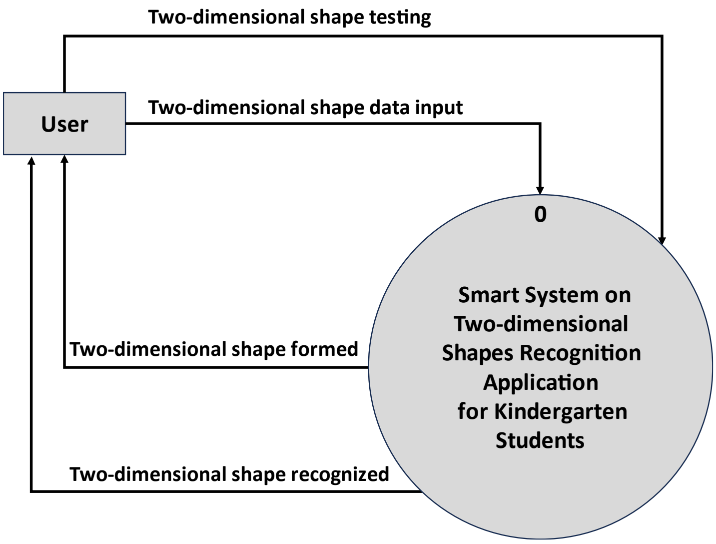

Figure 2. Context DFD for the two-dimensional shapes recognition application

The workflow of two-dimensional shape detection, a crucial component of the application design, is illustrated in Figure 3, utilizing the Harris method to detect corners or corner points on an object. The Harris method comprises five processes: image acquisition, segmentation, corner detection, center of mass and aspect ratio calculation, identification and highlighting.

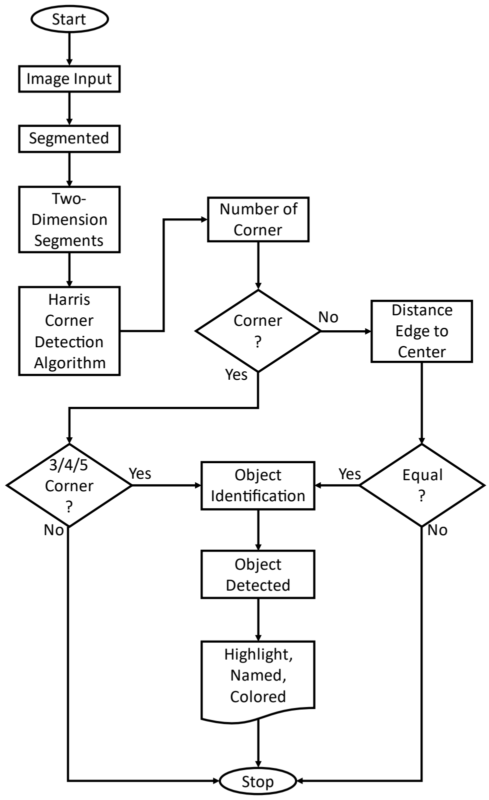

Figure 3. Two-dimensional shapes recognition application design

After the application is created and run on the smartphone, it appears as shown in Figure 4. On the left side of Figure 4 is the initial display, equipped with an explanation of flat shape recognition, including triangles or ‘segi tiga’, squares or ‘segi empat’, pentagons or ‘segi lima’, and circles or ‘lingkaran’. There are also buttons for Camera or ‘Kamera’ and Exit or ‘Keluar’. Selecting the ‘Kamera’ button activates the smartphone's camera to capture the desired object, resulting in an image like the one in the center of Figure 4. Next, press the confirmation button to perform the testing, as shown on the right side of Figure 4. It can be seen that triangles, squares, pentagons, and circles have been successfully detected and are highlighted in green, red, yellow, and blue, respectively. Objects detected elsewhere are outlined.

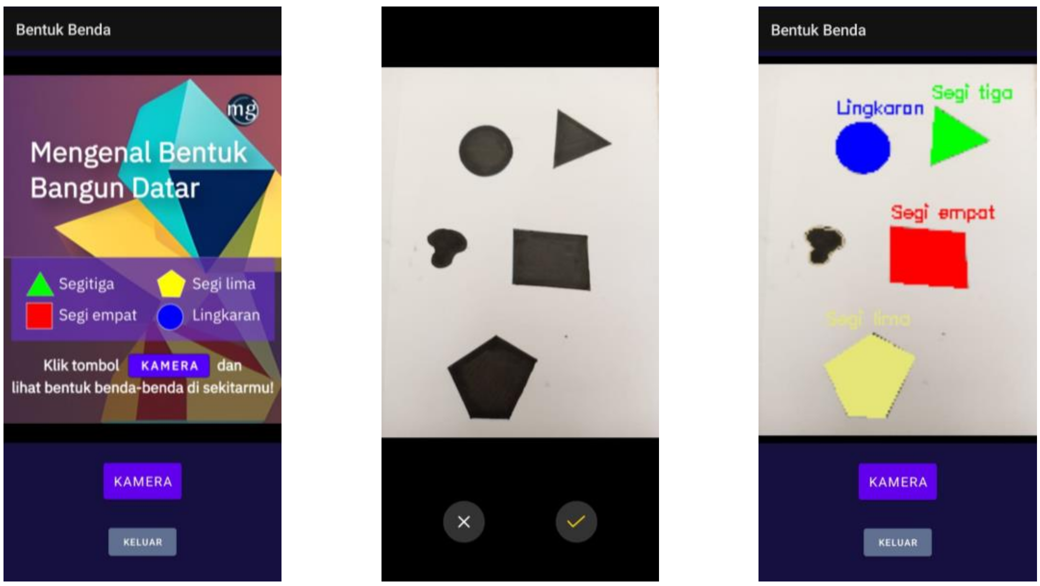

Figure 4. Application’s user interface

A summary of the data collection results and accuracy is presented in Table 1, with an accuracy value of 95/120 or approximately 79%. It is observed that the lower number of corners inversely correlates with accuracy, primarily due to low resolution or lack of focus, leading to simplified detected shapes.

Table 1. The recapitulation of data collection and accuracy

Two-dimensional Object	Number of Data	Accurate	Not Accurate
Triangles	30	27	3
Squares	30	25	5
Pentagons	30	23	7
Circles	30	20	10
Total	120	95	25

Image processing steps, which necessitate preprocessing with greyscale and binarization, lead to the loss of color information in the photo, causing the boundaries between objects in the image to become biased. Consequently, the application program can accurately detect objects with darker colors against a brighter background (closer to white) but struggles to detect objects placed on patterned or slightly darker backgrounds. The application also faces difficulties in detecting objects that do not contrast sharply with their backgrounds once they have been converted to greyscale, such as a green circle on a red paper. The quality of the smartphone camera sensor plays a significant role in its success, as an inaccurate sensor in capturing the true colors of objects can result in the same issues. This is why field tests with various makes and models of mobile phones yield highly variable results.

Regarding installation compatibility, there are no issues, and it is supported by mobile phones running Android [37] versions 9.0 to 12.0. The OpenCV [38]–[40] 4.6.0 library used is sufficiently compatible with the various Android versions used during testing. However, a drawback of using the OpenCV library is that it increases the size of the application and the application package (.APK) to a large size of 131 MB.
The rotational-invariant nature of contour detection means that the detected shapes do not have to be in an upright position. Triangular, square, and pentagonal areas that undergo rotation or other transformations can still be detected.

Table 2. Assessment of usability testing

Assessment	Teacher1	Teacher2	Teacher3	Teacher4	Teacher5	Teacher6	Average
Learnability	80	77	90	75	80	70	78,67
Efficiency	80	75	90	75	80	65	77,50
Memorability	75	76	90	85	80	75	80,17
Error Handling	70	72	90	90	80	60	77,00
Satisfaction	85	80	90	80	80	70	80,83
Average	78	76	90	81	80	68	78,83

From Table 2, it is apparent that the application has been well-received by its users, particularly kindergarten teachers, who have given it a favorable score of 78.83. This score indicates a positive reception and suggests that the application meets the usability and functionality expectations of the teachers.

Based on the results, this research has made a significant impact in two crucial areas. Firstly, it has introduced an innovative learning tool specifically designed for kindergarten students, utilizing smartphone technology to convert real-world objects into two-dimensional shapes. This tool fills a critical gap in educational resources for early childhood education, offering a unique approach to enhancing children's understanding of fundamental geometric principles. Secondly, the research contributes significantly to integrating technology into early childhood education. By recognizing the need for effective educational aids, particularly in helping kindergarten children grasp basic geometric concepts, this study provides a practical solution. Through the use of smartphone camera technology, it seamlessly merges modern technology with educational objectives, creating a more engaging and impactful learning experience for young learners. Overall, this research directly addresses challenges faced by kindergarten children in comprehending basic geometric concepts. Its rapid development of an innovative learning tool aims to bridge this critical gap in early education, paving the way for an improved educational journey and igniting children's motivation to grasp these essential concepts more effectively and enthusiastically.

CONCLUSION

This intelligent two-dimensional shape recognition system, tailored to the kindergarten curriculum, offers several advantages for both teachers and young learners. For educators, it provides a tech-savvy teaching aid that aligns with the ICT-based learning approach, enhancing their ability to engage students and make learning more interactive and engaging. Additionally, it streamlines the assessment of students' understanding of basic geometric shapes. On the other hand, for kindergarten students, the system fosters a fun and interactive learning environment, allowing them to visually explore and grasp fundamental shapes while promoting digital literacy from an early age. This technology not only aids in improving shape recognition skills but also encourages independent exploration, making learning an enjoyable and memorable experience. Overall, the system's integration into kindergarten education offers a promising avenue for enhancing both teaching and learning outcomes.

Despite its significant contributions, this research does have certain limitations that need acknowledgment. Firstly, the reliance on smartphone technology for object recognition might pose challenges in terms of accuracy and reliability, especially when dealing with diverse real-world environments. Variations in lighting conditions, object sizes, or occlusions might affect the system's effectiveness in accurately translating objects into two-dimensional shapes. Secondly, the study's focus on kindergarten students might limit the generalizability of the findings to other age groups or educational settings. Additionally, the evaluation of the learning tool's effectiveness could be further enhanced by incorporating a larger and more diverse sample of kindergarten students to ensure the tool's applicability across various learning contexts.

Looking ahead, future research endeavors could address the identified limitations and further advance the field. One potential avenue is to refine the smartphone-based object recognition system by integrating advanced algorithms or machine learning techniques to improve accuracy and adaptability to different environmental conditions. Moreover, expanding the scope of the study to include a wider range of age groups or educational levels could provide insights into the tool's effectiveness across diverse learners. Additionally, conducting longitudinal studies to assess the long-term impact of the learning tool on children's geometric understanding and academic performance could provide valuable insights into its sustained effectiveness. Exploring collaborative approaches between educators, technologists, and child psychologists to tailor the learning tool to diverse learning styles and cognitive abilities could also be a promising direction for future research endeavors. Overall, future research efforts should aim to address the identified limitations while exploring innovative ways to optimize the learning tool's effectiveness and applicability in enhancing geometric understanding among young learners.

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