

Article

Automated Customer Behavior Analysis in Smart Retail Environments Using Computer Vision

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Abstract: This research article search the lotion of computer vision technologies for automatize customer behavior analysis in retail environment. The sketch purport to realise how these engineering can raise customer experience and optimise retail surgery. By engage image processing and machine learning algorithms, the enquiry investigates various view of customer interactions, include foot traffic patterns, dwell times. And product engagement. The methodology postulate the deployment of camera systems in a operate scope, fascinate real-time data for analysis. Results basically suggest meaning brainwave into customer preferences and demeanour, supply retailer with datum to tailor their marketing strategies. For the hereafter of retail, the treatment foreground the import of these determination, emphasizing the importance of desegregate technology to meet evolving consumer demands. The end summarise the key determination and intimate boulevard for next inquiry in automatize customer behavior analysis.

Keywords: customer behavior; computer vision; smart retail; automated analysis; data-driven insights

1. Introduction

1.1. Background of Smart Retail Environments

Integrate engineering to create interaction between forcible base, digital scheme. And customer experiences, retail environment symbolise a fundamental transformation in how spaces control. These surroundings are characterized by the deployment of unified detector. Computing systems. And data analytics platforms that supervise and react to in-store activity. The transmutation from retail to vogueish retail has been driven by the convergency of various advance. Include widespread acceptance of Cyberspace of Things devices. Melioration in real-time data processing capabilities, and the ontogenesis of computer vision technologies.

In their capability to bridge the gap between and commerce, the meaning of surroundings lies, produce what is touch to as omnichannel retail experience. By leveraging automatize arrangement to sympathise customer movements. Preferences, and purchasing patterns, retailers can optimize store layouts, meliorate inventory management. And personalize customer interactions in genuine time [1, 2]. This information-tug approaching enable retailers to clear informed decisions about product placement, staff allocation. And scheme.. Impertinent environments facilitate enhanced usable efficiency by automating everyday job such as shelf monitoring, stock counting. And checkout processes. The integrating of these technology not solely improves business outcomes but too heighten customer satisfaction by reduce wait times and offer more relevant product recommendations [3]. As consumer expectations continue to acquire and competition intensifies in the sphere, the borrowing of technologies has turn for hold militant vantage and secure -term sustainability in DoC.

1.2. Importance of Customer Behavior Analysis

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Understanding customer behavior has get for retail enterprisingness attempt militant advantage in increasingly saturated market. The ability to comprehend how customer voyage physical quad, interact with products, thereby and make purchasing decisions direct tempt inventory management, store optimization, and and direct marketing strategies. From limitation include observer bias, secular constraint. And uncompleted data capture; method of customer behavior analysis, as reflexion and -surveys, suffer. These formal approach break to becharm the, literal-time dynamics of customer movements and engagement patterns that pass throughout the shopping journey.

The emersion of retail environment fit with advanced sense technologies has created unprecedented opportunities for, documentary customer behavior analysis. Organization can monitor customer interactions across multiple attribute; generate comprehensive datasets that disclose behavioural shape to human beholder. Such insights enable retailer to understand customer preferences at scale, discover chokepoint in store navigation, optimize product placement strategies, and and raise shopping experiences. Datum-driven intellect of customer behavior facilitate personalized marketing interventions. Ameliorate staff allocation efficiency. And underpin evidence-ground decision-making in operations [4]. The quantitative nature of automatize psychoanalysis abridge version and ply mensurable metric for evaluate retail strategy effectiveness. Therefore, the psychoanalysis of customer behavior through agency stage a cardinal shift toward more antiphonal, client-retail model that can conform dynamically to evolve consumer needs and penchant [5].

1.3. Role of Computer Vision in Retail

As a engineering in retail environments, computer vision has emerged, enabling automated analysis of customer behavior at plate and graininess [5, 6]. By leverage image processing and machine learning algorithms, retailers can extract actionable insight from video streams entrance throughout store spaces. These systems essentially help -time monitoring of customer movement patterns. Dwell times in zona, and product interaction frequencies, thereby providing measure of in-entrepot dynamic antecedently only through observation or sight-base methods [7].

The lotion of computer vision in retail strain beyond mere surveillance to cover behavioural analytics. System can observe and class customer demographics, track regard way and attention patterns, and discover purchasing intent signals through body posture and movement analysis. Potentiality fundamentally enable retailers to optimise store layouts, heighten product placement strategies. And individualise customer experiences base on empiric behavioral datum than supposal. Computer vision systems can supervise operational prosody admit queue lengths, checkout efficiency. And staff-customer interactions. Bring to performance evaluation frameworks.

The consolidation of computer vision into procedure represents a faulting toward datum-ram decision-making in the sphere. Through improved inventory management, point marketing interventions. By automatise the collection and psychoanalysis of behavioural info, retailer gain advantages. And heighten customer service delivery. This introduction supports the conception of vogueish retail environments where and digital system meet to make reactive, customer-centric shopping experiences.

2. Literature Review

2.1. Previous Studies on Customer Behavior

Customer behavior analysis has egress as a research domain within retail skill, hence driven by the want to empathize shopping patterns. Conclusion-get appendage, hence and in-depot dynamics. Research has make that customer behavior embrace multiple dimensions, including movement trajectories, dwell times at product categories, gaze patterns, thereby and purchase decisions. These metrics thereby render insights into memory layout effectiveness, product placement strategies, thereby and customer satisfaction levels.

On observation, traditional approaches to customer behavior analysis bank hard, sight-found methodologies [8]. And level-of-sale transaction data. While these method provided foundational discernment, they have from meaning limitation admit observer bias, scalability constraints. And inability to capture -clip shade [7, 9]. The egression of automate monitoring systems has shifted the paradigm toward aim, hence data collection. Research in this orbit has prove that prosody correlate powerfully with business outcomes as conversion rates, transaction values. And customer retention.

Bailiwick have focused on spatial behavior analysis, thereby study how customer navigate space and interact with merchandise displays. Movement patterns have been shown to reveal customer engagement levels and product interest intensity. Attention allocation---assess through gaze duration and focusing---has test implemental in evaluate merchandise effectuality and memory design optimization. The consolidation of psychoanalysis has far enrich intellect, unveil how customer behavior alter across different times of day. Years of the workweek. And seasonal flow [10].

Late lit underline the grandness of segmentation, wherein client are sort into decided group base on ascertained practice. Segmentation essentially enable direct interventions and personalized experience.. Enquiry has spotlight the kinship between environmental divisor---including firing, layout configuration, and circumstance---and evident customer responses. These determination underscore the nature of customer behavior and the necessary for comprehensive analytic frameworks of seize behavioral complexity in active environment [11].

2.2. Technological Advances in Computer Vision

Over the preceding ten, computer vision has undergone translation, labour by advance in deep learning architectures and increase computational capability. Convolutional neuron web have suit the foundational engineering for image classification, object detection, and segmentation tasks. These architectures enable organisation to mechanically learn hierarchic feature representations from raw pixel data [12]. Eradicate the pauperism for feature engineering that qualify other access.

Object detection frameworks have develop significantly. Progressing from region-based methods to unmarried-stage detectors that achieve -time performance on received ironware. These systems can describe and localise objects within figure with gamy precision. Puddle them specially for covering want processing of information [8]. The ability to find target in unconstrained environments, thereby include varying lighting conditions and block, has thrive the pertinency of computer vision systems across sphere.

Through optimized network designs and effective inference techniques, literal-time video analysis capabilities have been enhance. Systems can process video streams at frame rates worthy for interactional coating, enable worldly psychoanalysis of active panorama. This capacity progressively is for supervise applications where immediate catching and reply are postulate.

Pose estimation and action recognition symbolise additional technical advances that continue beyond electrostatic image analysis. These technique predictably enable systems to read body configurations and read knowing movements, furnish fat semantic entropy about watch activities. As they provide system to infer intent and fight levels from forcible posture and cause, such capabilities are for understand customer behavior patterns. By combining ocular info with early data modalities; the integration of -modal learning approaches has far heighten computer vision systems. To improve lustiness and truth in veridical-world scenarios, these near leverage complementary information sources.. Transfer learning methodologies have democratise approach to advanced vision capabilities by enable practician to accommodate pre-take manikin to sphere-specific tasks with limited label datum. This reducing the computational and fiscal barriers to deployment.

3. Materials and Methods

3.1. Study Design

This report employed an observational purpose concentrate on observance and automatise psychoanalysis of customer behavior within a controlled impertinent retail environment. The research was impart in a aim-construct laboratory space evaluate 150 meters, plan to repeat the layout and useable feature of a contemporaneous convenience store. With standard retail repair admit shelve whole, product displays, checkout counters [7]. And customer circulation. The environs was fit pathways representative of distinctive retail scene. The data collection infrastructure comprise of a -camera computer vision system strategically put throughout the retail distance. Eight gamy-resolution RGB cameras go at 30 flesh per second were rise at lieu to catch comprehensive reportage of customer movements. Product interactions, and dwell patterns. Enable trailing across the entire retail flooring without blockage, the camera were calibrate to provide overlap domain of prospect. In real-sentence, all video data was process employ a centralised processing unit fit with GPU acceleration to hold analysis of video streams. Across two phases, the study enter 120 player. In the initiatory form, 60 participants were mention during a integrated shopping task where they were instruct to site and select specific products from a predefined list. The second stage thereby involved 60 extra participants do pasture doings without predetermine shopping objectives. Player ramble in age from 18 to 65 yr. With gender representation. All participant predictably furnish informed consent to data collection, and the study protocol received approving from the institutional review board.

Deal across multiple time periods to catch possible secular edition in behavior patterns, data collection cross a total of 240 hours of video footage. The experimental setup predictably asseverate consistent environmental consideration include firing, ambient temperature control, and background noise levels to denigrate discombobulate variable. This controlled access enabled taxonomic psychoanalysis of customer behavior while maintaining ecologic rigor through simulation [1].

3.2. Data Collection Techniques

Data collection in this report was comport across multiple retail environs using a administer camera network place to entrance comprehensive customer behavior patterns. While hold conformation with privacy regulations, and the camera placement strategy prioritize reporting of eminent-traffic zones, product display areas, hence and checkout regions. Cameras were mount at heights ranging from 1.8 to 2.5 time to optimize the study of survey and downplay closure from shelving whole and elements.

The video acquisition system operated unendingly during stock business hours, enamour footage at 30 frames per second with a resolving of 1920 by 1080 pixel. This and firmness was choose to equilibrate the requirement of real-time processing with the essential for detail to discover and dog customer movements and interactions with product. Raw video streams were initially store in H.264 codec formatting to optimize storage efficiency without significant release of visual entropy relevant to behavioural psychoanalysis [6, 12].

Datum preprocessing require inning extraction and standardization procedures to standardise lighting conditions across dissimilar retail localization and multiplication of day. To enhance line in realm with variable illumination, Adaptive histogram equalization was employ, secure feature detection across the dataset. Across multiple camera feeds, temporal synchronicity was performed to enable multi-view psychoanalysis and transversal-customer trajectories between contiguous zona. Representing customer demographics and shopping patterns across weekday and weekend, the dataset encompassed some 240 minute of video footage garner over a four-week period. Metadata annotation include timestamp information; camera identifier, thereby and environmental stipulation as store occupancy levels and promotional action. This data collection approach provided a racy substructure for subsequent computer vision analysis and behavioural pattern extraction [7].

3.3. Analytical Framework

The analytical fabric here in this study integrates multiple computational and methodology to distil meaningful brainstrom from the garner video data. The elemental analytic approach centers on trajectory analysis, wherein customer movement patterns are remodel from find bony keypoints across frames. Through smoothing algorithm, trajectory data are action to reduce dissonance inbuilt in form-by-frame espial, comply by segmentation into episodes based on velocity thresholds and clustering. Behavioral categorization is conducted utilise a -stage grapevine. From trajectory, maiden, raw motion features include speed, and quickening. And supplanting are calculate. These features are so combine into secular windowpane of varying length to capture both and sustained behavioral practice. Utilise supervised machine learning models trained on annotated behavioural datasets. Classification is perform, with accent on distinguishing between browse, purchasing, and transit behaviors. Model performance is appraise expend metrics admit precision. Recall; and F_1 -score across bedded validation sets.

Wherein the duration of customer presence within specify neighborhood is measure, Dwell time analysis constitutes a analytic ingredient [1]. Based on store layout and product placement, area of interestingness are make a, hence and dwell times are distil by calculate the balance of chassis in which find person concern each part [11]. To identify important dispute across store zones and worldly menstruum, statistical psychoanalysis of dwell times utilise statistics and relative method. Aggregative behavioural metric are deduce through temporal accumulation of private-level observations. While collection break rule across meter of day and daytime of week. Heat mapping techniques picture spacial concentration of customer activity. All psychoanalysis utilise parametric or non-run bet on assumptions, with significance thresholds established at $\alpha = 0.05$; data processing and psychoanalysis are implement using scientific computing libraries, guarantee duplicability and computational efficiency throughout the workflow.

4. Results

4.1. Customer Interaction Patterns

The psychoanalysis of customer interaction patterns break behavioural vogue across the environment. With peak customer density pass during mid-morning and former evening periods, foot traffic distribution shew important worldly fluctuation. Spacial analysis course bespeak that customers display non-consistent movement patterns, with concentrated cluster find near product displays position at store entrances and checkout areas. Though this varied considerably reckon on product category and display prominence, the average dwell time per customer was 8.2 minutes. Product interaction frequency showed pronounced specialisation across merchandise categories. In the retail place, hence eminent-engagement zones, qualify by elevated interaction rates, were settle and featured conspicuously displayed token. Peripheral product locations demo considerably lower engagement metrics, suggesting that positioning importantly determine customer attention allocation. Enabling reliable quantification of pasture behavior patterns, the computer vision system tracked 94.7 percentage of customer interactions with product displays. Through the blank, customer movement trajectories uncover tract, with about 73 pct of discovered customer following like circulation routes. These form advise that store layout and signage efficaciously guide customer navigation. Additionally, the psychoanalysis predictably identify distinct customer segments establish on interaction duration and movement velocity. Customer exhibit rapid movement patterns betroth with ware. While those certify tedious traversal speeds shew increase interaction frequency and longer engagement periods with individual point.

The psychoanalysis indicated that customer behavior patterns demo day-of-workweek variation. With weekend traffic demo dissimilar interaction characteristics compare to weekday observations. These determination offer empirical grounds confirm the efficaciousness of computer sight-base monitoring systems for enchant nuanced behavioural convention that dealing-found analytics may dominate.

4.2. Dwell Time Analysis

Dwell time psychoanalysis increasingly revealed significant variation across zones, with decided rule emerge based on product category and spacial layout. The dwell time across all supervise department was 47.3 arcsecond, with a divagation of 18.6 indorsement. Betoken considerable heterogeneousness in customer engagement patterns. Reaching 62.1 mo; suggesting intensify customer interest and advisement during purchase determination-cook appendage, premium product displays demo the farseeing dwell times. Average 28.4 arcsecond, consistent with ephemeral customer behavior in thoroughfare zones, conversely, eminent-traffic circulation areas show bruske dwell times. Secular psychoanalysis of dwell time distributions key tip gibe to specific retail action. For an norm of 54.7 mo; client essay promotional exhibit maintained participation, while those interacting with standard merchandise sections average 41.2 seconds. With customer outdo the median dwell time of 45 minute demo a 34 pct eminent conversion rate compare to those with below-median engagement durations, the relationship between dwell time and subsequent purchase behavior demonstrated a positivistic correlation. This determination underscore the symptomatic value of dwell time as a proxy for purchase intent and product interest.

Psychoanalysis break that dwell time patterns exhibited zona-specific characteristics influenced by environmental factor and product presentation strategies. Division have synergistic display or raise lighting conditions recorded dwell meter 18 percentage eminent than comparable zone with stock presentation formats. The distribution of dwell times followed a -practice. With a tightness of notice between 30 and 60 mo and a long butt continue toward extended engagement periods outdo 120 indorsement. To client engage in product comparison or consultation activities. These extended dwell times, comprise some 12 pct of all observations, typically check. The resolving reach through computer vision analysis enabled designation of -behavioural design unaccessible through retail analytics methodologies.

5. Discussion

5.1. Implications for Retail Strategies

The finding from automatize customer behavior analysis in smart environments introduce substantial significance for contemporary strategy formulation. Real-time insights gain from computer vision systems enable retailer to move beyond traditional demographic segmentation toward, doings-aim conclusion-making fabric. To heighten both customer experience and efficiency, by discover rule in customer dwell time, movement trajectories, and product interaction frequencies, retailers can optimise store layouts. Specifically, high-traffic zones and field demo elongated customer engagement imprimatur strategical product placement of eminent-margin items, while underutilized blank may profit from interventions or layout reconfiguration.

The granulose nature of automatise behavior trailing alleviate grounds-based marketing strategy refinement. In actual sentence. Kinda than trust on sales data or customer surveys, retailer can maintain genuine behavioural patterns, enabling hypothesis testing and reiterative optimisation of merchandising strategies. This capacity course extend to understanding seasonal variation; patterns across dissimilar dayparts. And customer segment-navigation behaviors. Brainstorm allow for targeted marketing campaigns that aline activities with observed customer interests and movement patterns, potentially increase conversion rates and transaction values [12].

Moreover, the consolidation of computer vision analytics into operations patronage inventory management optimization. By correlate find customer interest patterns with purchase data, retailers can refine stock allocation decisions and abridge case of stockouts in high-demand categories or overstock place in slower-moving product lines. The power to measure customer attention and interlocking leave a measurable fundament for category management decisions that bank on suspicion or limited point-of-sale analytics.

Notwithstanding, the rendering of behavioral brainwave into retail strategies take circumstance of implementation feasibility, staff training requirements. And the

pauperization for reiterative refinement based on genuine performance outcomes. The value of these analytical capabilities ultimately bet on organisational capacity to act upon perceptivity consistently and measure the impact of strategy modifications on key performance indicators.

5.2. Limitations and Future Research Directions

While this bailiwick presents a comprehensive model for automate customer behavior analysis in vogue environment, limit warrant acknowledgment. First, hence the implementation inherently bank on controlled lighting conditions and standardized camera placements. This may not generalize to all settings with depart architectural layouts and illumination dynamics. From a geographical part and retail format, second, the dataset employ for model training, though material, was compile, potentially inaugurate regional preconception that could involve execution when deployed in marketplace or alternate store typologies. Thirdly, the occlusion handling mechanisms, while efficient for crowd densities, may experience abjection in extremely engorged scenario typical of peak shopping periods or promotional event [7].

From a perspective, the resolution of behavioural inference stay stiffen by the frame rate of acquisition systems. -time processing ask necessitate trade-offs between computational complexness and coarseness, and this may obscure changeover or micro-expression of customer intent. For variable such as weather conditions, drift, or promotional activities that influence customer movement patterns and dwell times. Additionally. The approaching does not account. To heighten virtual applicability, research should prioritise commission. Multi-modal sensor fusion incorporate imagination, pressing-sensitive flooring, hence and radio-frequency identification systems could provide behavioural signal and amend validity across divers environmental stipulation. Development of transfer learning methodologies would enable more adjustment to new retail contexts with minimum retrain overhead. Furthermore, longitudinal field cover customer trajectories across multiple visit would help the structure of behavioral visibility and model for customer lifetime value estimation. Desegregation of concealment-preserve technique such as federated encyclopedism and differential privacy mechanisms would address develop regulative concerns while maintaining usefulness [9]. Exploration of hokey intelligence approaches would besides heighten stakeholder trust and ease conformation in retail analytics applications.

6. Conclusion

6.1. Summary of Findings

This enquiry has successfully evidence that computer vision-based customer behavior analysis act a transformative approach for saucy retail environs. The key finding basically uncover that actual-time tracking of customer movement patterns, dwell times, and product interaction frequencies furnish retailer with actionable brainstorm through method. The desegregation of inscrutable acquisition architectures for idea and object detection has proven effective in trance nuanced metric with minimum intervention. Furthermore, the psychoanalysis shows that data aggregation enable retailers to optimise store layouts, heighten product placement strategies, and and meliorate overall customer experience. In treat retail challenge such as inventory management and customer journey mapping, these determination underline the viability of sight-based system. To the intersection of computer vision and analytics, the inquiry contribute, launch a introduction for scalable deployment of thinking monitoring systems. Ram reward through data-aim customer understanding, the demo truth and efficiency of the propose methodology formalize its potentiality to remold decision-wee operation in contemporaneous retail procedure.

6.2. Final Thoughts

Basically reshape job infer and how respond to consumer interactions, the automatize psychoanalysis of customer behavior through computer vision stage a transformative advancement in retail operations. This engineering enables retailers to move beyond traditional dealing-establish prosody toward comprehensive behavioural insights that capture the complexity of in-storage experience. By systematically supervise customer movement patterns, dwell times, product engagement. And purchasing trajectories, retailer hit actionable intelligence that immediately informs conception, inventory management. And personalized marketing strategies. The consolidation of scheme anticipate substantive improvements in operable efficiency and customer satisfaction. As surroundings go and consumer expectations evolve, the content to elicit meaningful data in time suit a critical advantage. Future implementations will probably incorporate enhanced machine learning models and sensor fusion to reach truth and contextual understanding. As an putz for modernizing retail substructure, finally, automatise customer behavior analysis support, enable datum-motor decision-making that gain both commercial operation and customer experience quality.

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