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STRUCTURAL LINE ORGANIZATION
AND FORM SEMANTICS OF SMART SHIRTS

This study investigates commercially available smart shirts for physiological monitoring and analyzes their structural seam line organization through ergonomics and form semantics. Nine products with monitoring modules positioned around the mid torso and one posture correction shirt were selected, and within a unified coordinate framework the front and back images were rectified for perspective and reconstructed as line drawings to map distribution patterns of key line groups, including the midline banded zone, shoulder to sleeve transition lines, side panel shaping seams, and opening and closure boundaries. The results show that concentrating logging modules and critical connection routes near the torso midline, together with a longitudinal band structure coordinated with a long shaping seam from the side chest to the waist, reduces lateral excursion during walking and running and keeps contact pressure on the anterior chest and upper back relatively stable. When curved raglan seams or a rear shoulder yoke is used, seams are shifted away from high slip regions such as the acromion and the lower edge of the armhole, which reduces the likelihood of friction, chafing, and pressure marks. When multiple sensing points are distributed across the chest, abdomen, back, and upper arm, a midline longitudinal band organization is more suitable as an alignment and fixation reference. In combination with a long lateral shaping seam, it preserves more continuous contact areas on the anterior chest and upper back, reducing detachment and displacement triggered by wrinkling. A center front zipper divides donning and doffing into shoulder and sleeve positioning and contact pressure build up, helping reduce torsional misalignment during wearing and stabilizing the distribution of contact pressure. At the appearance level, most samples mirror seam lines around the body midline, and continuous curves reduce sharp corners and short angular breaks. Longitudinal guidance and lateral contouring jointly strengthen the sense of motion direction, giving fixation and monitoring functions a clear technical orientation in appearance. Based on these observations, the paper summarizes zoning strategies and curve organization principles for smart shirts for physiological monitoring, providing traceable design grounds for subsequent seam line derivation and style comparison.

Key words: *Smart shirt, Structural seam line analysis, Ergonomics, Form semantics.*

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ОРГАНІЗАЦІЯ КОНСТРУКТИВНИХ ЛІНІЙ ШВІВ ТА СЕМАНТИКА ФОРМИ СМАРТ-СОРОЧОК

У цьому дослідженні вивчаються комерційно доступні розумні сорочки для фізіологічного моніторингу та аналізується організація їх структурних швів з точки зору ергономіки та семантики форми. Було обрано дев'ять продуктів з модулями моніторингу, розташованими навколо середньої частини тулуба, та одна сорочка для корекції постави. У рамках єдиної координатної системи зображення передньої та задньої частин були виправлені з точки зору перспективи та реконструйовані у вигляді лінійних малюнків для відображення розподілу основних груп ліній, включаючи зону середньої лінії, лінії переходу від плеча до рукава, шви, що формують бічні панелі, та межі відкриття та закриття. Результати показують, що концентрація модулів реєстрації та критичних маршрутів з'єднання поблизу середньої лінії тулуба, разом із поздовжньою смугастою структурою, скоординованою з довгим формувальним швом від бічної частини грудей до талії, зменшує бічне відхилення під час ходьби та бігу та підтримує відносно стабільний контактний тиск на передній частині грудей та верхній частині спини. При використанні вигнутих рагланових швів або задньої кокетки плеча шви зміщуються від ділянок з високим ковзанням, таких як акроміон і нижній край пройми, що зменшує ймовірність тертя, натирання та слідів від тиску. Коли кілька точок зондування розподілені по грудях, животу, спині та верхній частині руки, організація поздовжньої смуги середньої лінії є більш підходящою як орієнтир для вирівнювання та фіксації. У поєднанні з довгим бічним формувальним швом він зберігає більш суцільні зони контакту на передній частині грудей і верхній частині спини, зменшуючи відрив і зміщення, викликані зморшками. Центральна передня блискавка розділяє одягання і знімання на позиціонування плечей і рукавів та накопичення контактного тиску, допомагаючи зменшити викривлення під час носіння та стабілізуючи розподіл контактного тиску. На рівні зовнішнього вигляду більшість зразків відображають лінії швів навколо середньої лінії тіла, а суцільні криві зменшують гострі кути та короткі кутові розриви. Поздовжня орієнтація та бічне контурування спільно підсилюють відчуття напрямку руху, надаючи функціям фіксації та моніторингу чітку технічну орієнтацію у зовнішньому вигляді. На основі цих спостережень у статті підсумовуються стратегії зонування та принципи організації кривих для розумних сорочок для фізіологічного моніторингу, що забезпечує простежувану основу для подальшого визначення лінії швів та порівняння стилів.

Ключові слова: розумна сорочка, аналіз структурних швів, ергономіка, семантика форми.

Statement of the problem. Smart shirts integrate sensing contact points, lead wires, and logging modules into elastic fabrics, and both comfort and data quality are jointly affected by the stability of contact pressure and motion induced displacement. However, existing solutions lack a reusable framework for structural seam line analysis, making it difficult to explain how zoning and wire routing reach an actionable balance between fixation and comfort. This limits the abstraction and transfer of design experience, and design guidelines and operational evaluation methods that can directly inform practice have not yet been established.

Research analysis. Relevant studies over the past five years can be grouped into three streams, focusing on pattern generation and fit adaptation, the zoning logic of structural seam lines, and contact pressure with its evaluation. Work on pattern generation and fit adaptation is more oriented toward methods and toolchains. Lei (Lei G., 2022: 136) proposed a three dimensional pattern making method based on graphic encoding positioning, enabling three dimensional garment panels to be unfolded into two dimensional patterns more intuitively and efficiently. This method preserves the spatial locations of structural curves such as the body midline and the armhole with good fidelity, providing pattern making support for sensing point placement and wire routing fixation in a smart shirt for physiological monitoring. Based on 126 virtual try on models, Choi (Choi J., 2025: 30) identified four categories of issues, including proportions, level differences, lateral posture, and shoulder imbalance,

and then built a library of 48 shirt patterns optimized for different body types. This provides a basis for revising the base block pattern of a smart shirt for physiological monitoring, improving seam alignment and fit stability, which in turn benefits sensing point fixation and wire routing constraints. Studies on the zoning logic of structural seam lines are more oriented toward design rationale. Using seam lines as the entry point, Wang Qi (Wang Qi, 2013) proposed that compression sport shirts should define zones according to muscles, sweat zones, dermatomal structures, and skin folds, in order to secure fit and functional performance. The study grouped functional zones into moisture management and athletic performance enhancement, and it highlighted alignment based seam segmentation to reduce soft tissue vibration and displacement, which can be used to derive stabilization strategies for sensing point placement and wire routing in a smart shirt for physiological monitoring. Evidence on contact pressure and its evaluation is more oriented toward quantitative support. Goncu-Berk G. (Goncu-Berk, G, 2021: 5621) compared the impedance and signal to noise ratio of embroidered textile electromyography electrodes across raglan sleeves and set in sleeves, as well as across different fit levels. Their results indicate that pattern design and fit level determine the stability of electrode to skin contact. Liu Liying (Liu L., 2013: 60) conducted regression analysis between subjective comfort ratings and laboratory based objective indicators. The indicators most strongly associated with comfort were water vapor transmission rate, air permeability, fabric modulus, and drape index, and these can serve as quantitative grounds for material selection and fit control in a body fitting smart shirt for physiological monitoring. Li Yufen (Li Yufang, 2021: 52) used surface electromyography features, including root mean square, integrated electromyography, median frequency, and mean power frequency, as evaluation indicators for garment pressure and fit effects in yoga wear. The study found that moderate garment pressure can suppress fatigue, whereas pressure that is too low or too high increases fatigue, suggesting that a smart shirt for physiological monitoring should use moderate pressure to stabilize sensing points while avoiding constrictive pressure.

Purpose of the article. Using multiple smart shirts for physiological monitoring as samples, this paper examines structural seam lines such as the neckline curve, shoulder line, side seam, and chest circumference control line, maps their zoning and curvature directions in front and back views, discusses their roles in sensing contact point positioning, fabric fit, and suppression of motion induced displacement, and then summarizes transferable design principles from the perspective of visual order, providing interpretable grounds for subsequent design derivation and evaluation.

Presenting main material. This study selected ten smart shirts with relatively high market sales as samples. To obtain comparable structural seam line data, high resolution front and back images of each shirt were collected, with priority given to materials showing a natural standing posture and limited lens distortion, and perspective and geometric distortion corrections were then applied. Under a unified reference frame, the images were scaled and aligned proportionally, and the silhouette, key seam lines, opening and closure locations, and functional zone boundaries related to sensing elements or device modules were traced and organized in vector form. To reduce errors introduced by any single image, each product was cross checked against images from multiple angles to verify seam line relationships and to ensure consistent relative positions between line trajectories and anatomical landmarks. Afterward, the line drawings were mapped onto a standard human body model, which supported the classification of structural seam line types and zoning features and was used for subsequent analysis of structural zoning, load transfer paths, and potential friction prone areas.

The core modules or anterior chest contact points of Zephyr, QUS, Cardiosport, and Clicshirt are concentrated near the torso midline (Table 1). The logging modules of Zephyr and QUS are positioned on the upper back midline, while the chest contact points of Cardiosport and Clicshirt are located near the anterior chest midline. During walking and running, the midline region shows smaller lateral excursion, so the contact pressure at chest contact points is more stable. In all four shirts, the shoulder seam lines avoid the apex of the acromion and the edge of the underarm. In Cardiosport, Clicshirt, and QUS, the shoulder uses curved seaming that transitions from the neckline toward the underarm. Zephyr introduces a transverse seam across the rear shoulder, placing the seam on a flatter posterior shoulder area and away from the boundary with greater anterior axillary slip. During arm swing, the anterior axilla and the underarm show greater skin–garment slip, and moving seams away from these regions reduces the risk of friction and pressure marks.

Hexoskin, Emglare, Athos, and Keesense place multiple sensing contact points across the chest, abdomen, back, and upper arm (Table 2). With sensing points distributed, fit cannot rely on a single anterior chest area. Structural seam lines need to secure multiple contact points within relatively stable fab-

ric regions. In all four samples, a longitudinal band organization appears near the torso midline, serving to accommodate wire routing or fix modules while also acting as an alignment reference between front and back components. On the back of Athos, Emglare, and Keesense, a banded zone extends vertically along the back midline, and nodes or connection points are arranged around this zone. Hexoskin has fewer seam lines, and two horizontal fixation bands on the front directly define the positions of the sub chest and waist abdomen contact bands. Sensing contact points are mostly located at the central anterior chest and central upper back, and continuous fabric is typically preserved near the anterior axillary edge and the lower edge of the armhole to avoid placing contact points in regions with stronger arm swing compression and frequent wrinkling. The shoulder region often uses curved shoulder to sleeve segmentation or a vest like armhole boundary, keeping seams away from the acromion apex and the lower armhole edge and reducing chafing and local peak pressure during arm swing. A shaping seam from the side chest to the waist provides the primary contouring. Around the anterior chest and upper back contact zones, fewer seams reduce wrinkling, which makes patch edges less likely to lift and results in more stable contact.

Table 1

Tructural seam lines and functional zoning of smart shirts with a centralized logging module

Zephyr Smart shirt	QUS Smart shirt
Cardiosport Smart shirt	Clicshirt Smart shirt

Table 2

Structural seam lines and functional zone distribution of smart shirts with multi-point sensing

Emglare Smart shirt	Hexoskin Smart shirt
Athos Smart shirt	Keesense Smart shirt

OWO and Posture Shirt use a center front zipper and are designed for posture and haptic feedback (Table 3). If a pull over design is used, a larger stretch is required to achieve the same contact pressure, and the shoulder and armhole are more likely to shift out of alignment during donning and doffing. A center front zipper divides the process into positioning and closure, allowing the wearer to align the shoulder and armhole first and then close the zipper gradually to build pressure. With positioning before closure, repeated pulling near the shoulder and armhole to search for alignment is reduced, and local constrictive pressure caused by fabric torsion decreases accordingly. Once the opening and closure structure is anchored on the torso midline, lateral sway during movement is smaller and the anterior chest pressure distribution becomes more stable. Both shirts place the primary contouring within side panel structures from the side chest to the waist, while keeping more continuous fabric surfaces on the anterior chest and upper back, which reduces contact point drift and stabilizes the direction of tensile guidance. Shoulder seam lines are kept away from high friction boundaries such as the acromion and the lower edge of the armhole, reducing chafing and pressure marks during arm swing.

Table 3

Structural seam lines and functional zone distribution of smart shirts for posture and haptic feedback

OWO Smart shirt	Posture Shirt

Both the neckline and the armhole are finished with continuous curves, with few sharp corners or short angular breaks. Zephyr, Hexoskin, and Keesense are sleeveless models, where the neckline and armhole are mostly closed by a single curved line, and the armhole curve transitions continuously from the anterior axilla to the front shoulder without corner points. The remaining sleeved models use a raglan construction, in which the raglan seam extends from the side of the neck to the underarm as a continuous curve, making the shoulder point angle less pronounced. In Athos, QUS, and Clicshirt, the raglan seam curvature is relatively consistent, and the seam does not fall near the acromion apex. OWO and Cardiosport incorporate an opening and closure structure at the center front, while the shoulder area still maintains the continuous curvature of the raglan seam. In Athos, OWO, and Emglare,

the starting point of the raglan seam lies closer to the side of the neck, resulting in a fuller lateral shoulder contour. In Cardiosport, the shoulder line is positioned more laterally, its upper edge is closer to horizontal, and the shoulder contour appears straighter.

The curve design of the ten smart shirts is often organized around the body midline, where left–right mirrored lines treat the body as a coordinate system and establish a stable and predictable visual reference. For wearable devices, this sense of order is naturally interpreted by users as reliability and controllability, giving the appearance a rational technological character.

In most samples, structural seam lines show clear anatomical orientation. The line organization of Keesense and AlignMed more closely reflects abstractions of muscle bundles and bony landmarks, where anterior chest lines branch downward and back lines converge toward the midline, creating a progressive tightening direction from the chest and back toward the waist and making support relationships more legible in form. Cardiosport uses lateral contouring and zoning lines to emphasize a forward driving momentum, whereas the back midline and horizontal banded lines in Zephyr and QUS strengthen guidance for alignment and stability. Across these samples, seam lines often follow the outer contour of the rib cage and the shoulder – back outline, and large radius curves connect regions with different curvatures; on the front, lateral inward shaping achieves close to body contouring, while on the back, longitudinal and oblique line organizations provide alignment and constraint. This makes the intentions of fit and support visible on the garment surface and produces an overall second skin impression.

While maintaining close fit to the body, structural seam lines also guide how motion is expressed in the shirt's appearance. In Zephyr and QUS, the combination of the back midline and horizontal banded lines forms a clear longitudinal frame. As the lines descend along the spine, the back structure reads visually as a stable channel, making the wearer's torso posture easier to track during running and jumping. Cardiosport uses lateral contouring curves and zoning lines to redirect the silhouette from the chest toward the waist side. Because the lines slide diagonally downward, the front view more readily evokes a body posture that moves forward. Athos adopts a symmetric network of nodes and connecting lines, dividing the chest and back into multiple smaller geometric units. The sense of motion no longer depends on a single dominant curve but arises from rhythm created by repetition and spacing variations in the mesh structure. As the gaze moves, the nodes create a sequence of continuous pause points. The connecting lines mark load directions of outward expansion and inward recovery across the chest and back surfaces, making the garment read more like equipment with a functional frame. Hexoskin uses fewer seam lines and mainly relies on the overall silhouette and a small number of horizontal stabilization bands to control rhythm. With fewer distracting surface elements, the impression leans toward a tool like and low intervention character. These strategies rely on midline guidance, lateral contouring, mesh segmentation, and simplified linework, and they shape different motion atmospheres on top of a body fitting pattern. Some emphasize posture alignment, some highlight forward progression, and others foreground an equipment like character or low perceived presence, providing clear formal cues for stylistic differences under similar functional goals.

Conclusions. This paper examines commercially available smart sports shirts with rear mounted monitoring modules, and under a unified coordinate framework it performs image rectification, line drawing reconstruction, and seam line overlay, in order to map seam line types and combination patterns from ergonomic and visual cognition perspectives. The findings show that outer silhouettes often use large radius curves and rounded edge finishing, which helps maintain fit during movements such as running and jumping and reduces pressure marks and chafing around the shoulder–neck region and the underarm. The continuous connection between the under chest band and the lateral regions forms the primary load bearing path, redistributing module weight and fabric tension around the torso circumference and relieving local pressure concentration. Monitoring module pockets are concentrated along the back midline and paired with several stable cable routing path configurations, supporting signal stability, skin comfort, and visual neatness during dynamic movement. Across samples, differentiated strategies are formed through midline guidance, lateral contouring, mesh like segmentation, and simplified linework, enabling motion semantics such as posture alignment, forward progression, equipment like character, and low perceived presence to be clearly distinguished on a shared functional basis. On this basis, the paper extracts transferable curve categories and configuration principles that can be used to describe pattern logic and visual expression across products.

BIBLIOGRAPHY

1. Lei, G., & Li, X. A new approach to 3D pattern-making for the apparel industry: Graphic coding-based localization. Computers in Industry, 2022, 136, 103587. https://doi.org/10.1016/j.compind.2021.103587

2. Choi, J., Choi, H.E. Development of a body type optimized pattern library based on fit adjustment frameworks. Fash Text 2025, 12, 30 . https://doi.org/10.1186/s40691-025-00437-8

3. 王琦. (2013). 紧身型运动服装分割线设计研究: 硕士论文. 北京服装学院, 北京, 中国, 2013. 22-30.

4. Goncu-Berk, G., & Tuna, B. G. . The Effect of Sleeve Pattern and Fit on E-Textile Electromyography (EMG) Electrode Performance in Smart Clothing Design. Sensors, 2021, 21(16), 5621. https://doi.org/10.3390/s21165621

5. 刘丽英 & 刘林. 服装舒适性主观评价及主客观指标间的相关性研究. 青岛大学学报(工程技术版), 2013, 28 (03), 60-63+68. https://doi.org/10.13306/j.1006-9798.2013.03.003.

6. 李玉芬 & 朱卫华. 服装压对瑜伽运动中女子上身肌肉疲劳的影响. 毛纺科技, 2021, 49 (06), 52-57. https://doi.org/10.19333/j.mfkj.20201000406.

REFERENCES

1. Lei, G., & Li, X. (2022). A new approach to 3D pattern-making for the apparel industry: Graphic coding-based localization. Computers in Industry, 136, 103587. https://doi.org/10.1016/j.compind.2021.103587

2. Choi, J., Choi, H.E. (2025). Development of a body type optimized pattern library based on fit adjustment frameworks. Fash Text 12, 30. https://doi.org/10.1186/s40691-025-00437-8

3. Wang Qi. (2013). Jin shen xing yun dong fu zhuang fen ge xian she ji yan jiu [Research on the Design of Seams in Tight-Fitting Sports Clothing]: Master's dissertation. Beijing Institute of Fashion Technology. Beijing. China. 22-30. URL: https://kns.cnki.net/kcms2/article/abstract?v=NitQnVYDOcrSavugUjhfyQWlB26cyHpaekhbyqHidiK-y3XNdl2K4s2dt2FQx9_eVVer12WbW5L34b8eLGFZY9pSrKsNyVUynaeCrA3IURw7X5RDlsK2WqQdRPxV336kYVdRDKIdn2PlFtM-QarVTzfTR681oOyTwKshTz_EjSvEmxy2DXASLw==&uniplatform=NZKPT&language=CHS". [In Chinese]

4. Goncu-Berk, G., & Tuna, B. G. (2021). The Effect of Sleeve Pattern and Fit on E-Textile Electromyography (EMG) Electrode Performance in Smart Clothing Design. Sensors, 21(16), 5621. https://doi.org/10.3390/s21165621

5. Liu Liying, & Liu Lin. Fu zhuang shu shi xing zhu guan ping jia ji zhu ke guan zhi biao jian de xiang guan xing yan jiu [The Study on the Subjective Evaluation of Clothing Comfort and the Correlation between Subjective and Objective Indicators]. Journal of Qingdao University(Engineering & Technology Edition), 2013, 28 (03), 60-63+68. https://doi.org/10.13306/j.1006-9798.2013.03.003. [In Chinese]

6. Li Yufang, & Zhu Weihua. (2021). Fu zhuang ya dui yu jia yun dong zhong nv zi shang shen ji rou pi lao de ying xiang [The impact of clothing pressure on the fatigue of women's upper body muscles during yoga exercises]. Wool Textile Journal, 49 (06), 52-57. https://doi.org/10.19333/j.mfkj.20201000406. [In Chinese]