Gehna: Exploring the Design Space of Jewelry as an Input Modality

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Figure 1: Gehna or jewelry ornaments that are regularly embraced on different body parts enable a rich space of wearable based input.

ABSTRACT

Jewelry weaves into our everyday lives as no other wearable does. It comes in many wearable forms, is fashionable, and can adorn any part of the body. In this paper, through an exploratory, Research through Design (RtD) process, we tap into this vast potential space of input interaction that jewelry can enable. We do so by first identifying a small set of fundamental structural elements — called Jewelements — that any jewelry is composed of, and then defining their properties that enable the interaction. We leverage this synthesis along with observational data and literature to formulate a design space of jewelry-enabled input techniques. This work encapsulates both the extensions of common existing input methods (e.g., touch) as well as new ones inspired by jewelry. Furthermore, we discuss our prototypical sensor-based implementations. Through this work, we invite the community to engage in the conversation on how jewelry as a material can help shape wearable-based input.

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CCS CONCEPTS

• **General and reference** → **Design**; • **Human-centered computing** → *Ubiquitous computing*.

KEYWORDS

Jewelry, Wearable-based input, Interaction Design

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1 INTRODUCTION

Jewelry comes in a myriad of forms ranging from a simple platinum band to Deepika Padukone's exaggerated, meticulously crafted ornaments from the movie *Padmaavat*[1]. Further, it is used to adorn almost all locations on the body. As interaction designers, we are excited to imagine the huge possibilities that jewelry can enable for wearable-based input (Figure 1). Inspired by previous efforts in taking inspiration from objects in the physical world to design technology [20] and learning from design research stating how physical instruments can scaffold the process of inquiry [6], we look to explore as to how jewelry as a material can help shape wearable-based input. To do this, we explore a new form of *digital jewelry* [29] that augments a variety of touch, jewelry manipulation interaction gestures.

This work is a novel outcome of parallel evolution of digital jewelry and ongoing research on wearable-based input in ubiquitous computing. Digital jewelry was first explored by multinationals including IBM, Nokia and Philips, who sought to create more aesthetic, socially-acceptable wearables [7, 29]. The existing smart jewelry products (like smart watches [24], smart rings [36]) are a manifestation of these initial efforts. Combining high fashion jewelry artifacts with functionalities including time-keeping, fitness tracking, mobile notifications and safety in this manner had led to good commercial success [39]. At the same time, researchers following Mark Weiser's vision of ubiquitous computing [50] have been actively looking into new forms of on-body input to enable always-available, eyes-free interaction [2, 12]. To the best of our knowledge, this is the first work that taps the rich opportunity of weaving a broad study of jewelry of different styles with explorations of input interactions based on its physical affordances, and on-body placement.

We followed an exploratory, Research through Design (RtD) method [11, 54]. We started by exploring a sample set of jewelry artifacts collected from *Dariba Kalan*, one of the oldest jewelry market in New Delhi, India. Based on this analysis, by bringing in perspectives from the literature on jewelry design and making [43], we defined a set of basic structural elements (called *Jewelements*) and their properties that enabled the interaction. Similarly, for various body locations that jewelry is worn on, we identified a set of features that allowed specific actions. Finally, we augmented our sample artifacts to sense these actions using suitable prototypical methods. In this paper, we demonstrate this process, by first sharing the accumulated knowledge as a *taxonomy of jewelry design*, and then expanding upon our design explorations with the sample artifacts. We conclude by presenting example applications that utilize jewelry for input.

[1]https://www.tanishq.co.in/padmaavat/collection

In summary the main contributions of this work are:

(1) We present a taxonomy of jewelry design that classifies jewelry on basis of the constituent jewelements and the body location which it is worn on.
(2) Based on the taxonomy, we present our explorations on a new form of digital jewelry that augments a variety of touch, jewelry manipulation gestures.
(3) Finally, we present a set of speculative applications that can utilize these gestures.

2 RELATED WORK

Our work falls within the category of digital jewelry. Further, we review existing work on wearable-based input to access implications of our research.

Digital Jewelry

The term digital jewelry refers to adornment artifacts that function both as a jewelry and as a computational device [29]. This concept came into existence in the late 1990's to satisfy the increasing demand of more aesthetic, personal and social wearable devices [29]. Researchers at IBM Research envisioned jewelry as the "carrier for technology." They explored a jewelry-based mobile phone set with the microphone fitted into a necklace and speakers fitted into earrings [34]. Similar explorations were also done by other multinationals including Nokia and Philips [7]. Jewelers and design-researchers with a jewelry background had a significantly different take on digital jewelry. They focused on the poetic qualities of interaction with jewelry like enchantment, sensorial engagement, and intimacy (towards other people, places and self) [45]. An early example of these effort was the *for two rings* designed by Nicole Gratiot Stober [25]. Set of two rings on lovers glowed when they touched their hands. Another example is the work of Jayne Wallace, who integrated technology into jewelry with the aim of creating artifacts of emotional, personal significance to the wearer[27].

Silina et al. in their survey of this field noted that much of these efforts were not able to pull the attention of the customers [39]. Since 2012, however, she notes, products of digital jewelry have flooded the market, operating primarily in the wellness, sports & fitness segments. *Ringly* [36], *Oura* [1], and *Access* [24] by Michael Kors are some of the popular products, based on the ring, watch form-factor. In research, there have been recent efforts to create digital jewelry that enriches the intimate, emotional and social effects of traditional jewelry, in line with the early efforts made by jewelers. Using craft based inquiry, Research through Design methods, researchers have presented a series of explorations such as sound-locket memento, hard drive pendant and hand-made LED hair needle [41, 44].

Taking a different route, we instead focus on the physical form of jewels, how they are worn on the human body, and utilize these factors to design jewelry-enabled interactions. Insel et al. have published their proposal to use similar qualities of jewelry for prototyping smart wearables [18]. They intend to create a wearable design toolkit, consisting of basic functional blocks (like LED, sensors) modeled as primitive jewelry elements. We instead utilize the qualities as the basis for designing touch, manipulation interactions enabled by available jewelry artifacts.

Expanding Wearable-based Input

Moving towards Mark Weiser's vision of merging computers in the "fabric of everyday life," [50] body of research in wearable and ubiquitous computing has conducted rigorous explorations in finding new forms of wearable-based input [2, 12]. Human body has been considered to offer a large and quickly accessible surface for always-available, eyes-free interaction [13]. Thus, researchers have explored input techniques based in human skin [32, 33, 46], finger nails [21], clothing [35], cheeks [38], ears [26], and human hair [8], apart from jewelry. Along with ubiquity and eyes-free interaction, subtleness and privacy of input gestures [3, 5], their emotional richness [47] have been common goals of defining these interaction techniques.

The first significant interaction paradigm within these efforts includes on-body touch interaction. In some of these designs, wearable devices (like watch [16], ring [52] or arm band [30]) are used to pick up on-skin touch input performed in their proximity using magnetic [3, 16], acoustic [14, 52], ultrasonic [30], and infrared reflection [33] techniques. Other designs rely on capacitive sensing based touch activated skin overlays that adhere to the skin as tattoos [22, 46, 48]. A second important interaction paradigm deals with physical manipulation or deformation input on skin, ear lobe, clothing or elements of the wearable device itself (like chords, flexible sphere, etc.) [23, 26, 33, 37, 47, 49]. It is worth noting how the flexible form-factor of the target material enables this category of interaction. Researchers have highlighted miniaturization [31] and higher expressiveness as major reasons to prefer deformation input over other modalities (such as touch) [49]. In this work, we use jewelry to enable a variety of touch and manipulation interactions.

3 TAXONOMY OF JEWELRY DESIGN

In this section, we define a taxonomy of jewelry design (Figure 2) that sets the premise for presenting our digital jewelry explorations in the next section. We start by enlisting a set of common jewelry findings or *Jewelements* that constitute almost all jewelry artifacts. We then discuss jewelry in context of the various body locations that it goes on.

The basis of this taxonomy lies in existing literature on jewelry design [40, 43], making processes [28, 51], the online archives of websites that are centered in jewelry related practices (e.g., *rio grande*[2], *anthropologie*[3]), and in our hands-on study of a sample set of artifacts that we had collected from Dariba Kalan jewelry market. Initially, we selected the artifacts that covered most body parts, had different styles, and seemed unique. As we moved through the process of creating this taxonomy, we searched for newer artifacts that exemplified some interesting design features that we observed in jewelry design literature. The final set comprised of 30 artifacts: 2 nose pins, 11 pair of earrings, 6 necklaces, 2 upper arm bracelet, 3 lower arm bracelet, 2 set of bangles, 3 finger rings and a pair of anklets. Reader must note that we were admittedly biased towards specific jewelry types that enabled novel interactions. For instance, we laid more emphasis on *extremely flexible* jewelry than *permanently rigid* artifacts (as per Untracht's classification [43]), as this kind of jewelry enabling deformation via the human hand, can be manipulated to perform gestures. Similarly, this taxonomy is slanted towards contemporary, commonplace jewelry, rather than artifacts of historical or cultural significance.

Common Jewelry Findings

Jewelry findings are the basic parts used to construct jewelry.

Chains. Chains have a long history of use in jewelry, both to support other elements like pendants or bracelets and as a decorative element in itself [51]. In its most basic form, a chain is a mechanical assembly of similar shaped metallic rings (called *links*) that intercept or pass through one or more preceding units. There exists a huge variety in designs of a chain based on the choice of the link element, ways in which they are assembled together (Figure 2.A). What is common though is the slinky, flexible character of a chain that makes it one of the most delightful jewelry element to explore. We are most interested in the element of motion that chain enables for the jewelry artifacts — one can grasp one end of a chain and can move it in the 3D space. We refer this property as *slack* in the proceeding sections.

Beads. Beads are a characteristic jewelry finding. These come in a variety of shapes like round, donut, saucer, etc. and have a cylindrical drill that allows the passage of a chain, a thread or a ring — to suspend the bead (Figure 2.B). The size of a bead determines the way it which it can be handled, the touch interactions that it can support. While a small, round bead (dia 6mm) allows a two-finger grasp, a larger saucer shaped bead can support finger swipes along its length. When suspended, a bead can be freely rotated along the axis of its drill.

[2] https://www.riogrande.com
[3] https://www.anthropologie.com/jewelry

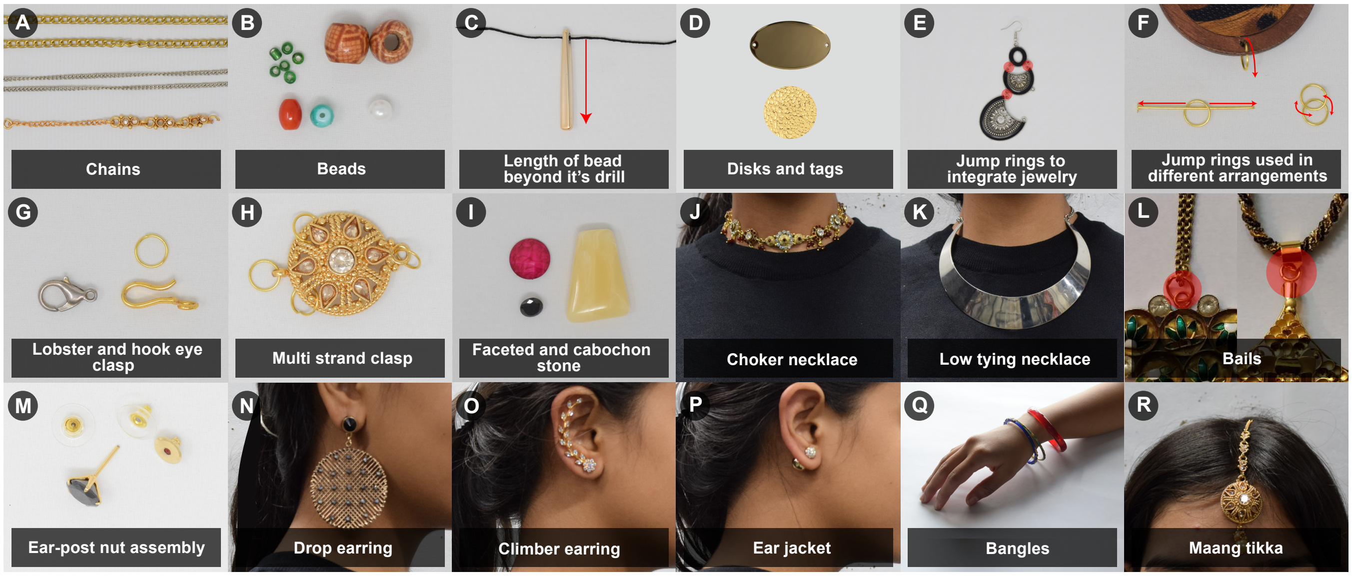

Figure 2: Taxonomy of jewelry classification

The extension of length beyond the drill center affects how a user can do this manipulation (Figure 2.C).

Disks and Tags. These are thin metal plates that can be used as a decorative element (Figure 2.D). Like beads, the *shape* and *size* of these entities can determine the kind of touch interactions that they support.

Jump rings. Jump rings are small circles of wire that are used for "jumping" the gap between parts i.e. to integrate two distinct parts together. They form the basis of what Untracht had defined as *extremely flexible* jewelry [43], where the total unit consists of distinct segments that are united together (by jump rings) to form flexible joints (Figure 2.E). Although there are infinite ways of how jump rings can be used in an artifact, figure 2.F shows the few arrangements that we observed, with the degrees of motion that each of them enables.

Clasps. Clasps are used for *holding* jewelry artifacts like necklaces or bracelets on the respective body locations. Structurally, they consists of two complementary parts that fit together and can be manipulated to release the hold when the jewelry is to be removed. While clasps come in a variety of forms, *hook and eye* and *lobster* clasp are the common ones (Figure 2.G). A *multi-strand* clasp has multiple rings for making connections (Figure 2.H).

Stones. Stones come in two main forms: faceted or cabochon (Figure 2.I). While faceted stones have a flat face, cabochon stones have curved, convex surfaces. We observed these surfaces to allow space for touch interaction. Being mounted in rigid assemblies, these stones in general don't provide the possibility for any manipulation.

Jewelry and Human Body

In this subsection, we discuss the jewelry worn at different locations on the human body i.e. on neck, ears, limbs, waist, and head. We illustrate how the anatomy of these body parts leads to functional considerations for the design of the respective artifacts, hence providing us cues for designing jewelry-enabled interactions.

Neck. Jewelry worn on the neck is referred to as necklaces. Necklaces are worn either close round the throat, loosely around the neck, or low down on the chest [40]. Necklaces worn round the throat are generally referred to as *choker* necklaces (Figure 2.J). Necklaces that lie loosely on the neck generally taper towards the sides for stability (Figure 2.K). These artifacts have a clasp systems for wearing, removing from the body. Among the necklaces that lie low down on the chest, *pendant necklaces* are fairly common. These artifacts include a chain, a central, decorative piece called a pendant that connects to the chain through a bail (Figure 2.L).

Ear. Jewelry worn on the ear is referred to as earrings. Most earrings are worn on the ear through piercings on the lobe, the soft, bottom most part of the ear. Earrings can loosely be classified into stud, drop, climber and jacket earrings. *Studs* refer to small pieces, typically expensive stones, that are worn into the piercing through a ear-post, nut assembly (Figure 2.M). *Drop* or *dangler* earrings "drop" below the ear lobe (Figure 2.N) and are usually worn using an ear-wire.

Climber earrings "climb" up the lobe along the shape of the ear (Figure 2.O). Ear *Jackets* adorn the outer and the inner sides of the ear lobe (Figure 2.P). It is of interest to note how ear-post and ear-wire passing through the piercing hole, form an assembly similar to a jump ring hole arrangement shown in figure 2.F, and hence allow motion. Apart from the structure of the earrings, the flexibility of the ear lobe turned out to be an important factor during our explorations of designing jewelry-enabled interactions.

Limbs. Jewelry worn on the limbs includes finger rings, bangles, watchbands, and upper-arm bracelets for the arm, toe-rings and anklets for the legs. All of these artifacts manifest a *cylindrical* form as per Untracht's classification of jewelry [43]. Cylindrical ornaments curve around the body part which they adorn. Other jewelry types within Untracht's classification are *frontal*, and *three-dimensional*. The pendant of a necklace is an example of the frontal form, wherein, once worn, their front side is displayed while the back side stays in contact with the body. Similarly, the drop earring, as it hangs down, exemplifies the three-dimensional form.

The form of jewelry thus classified helps us define the interactions it can support. For instance, frontal ornaments, because they lay flat against the body, are ideal for touch interaction. Similarly, cylindrical ornaments are sized jewelry, with sizes specified relative to the range of sizes of the respective body part. These size constraints are necessary to hold the jewelry in place and to facilitate the act of wearing the artifact. For instance, a bangle has to go through the hand before it then sits loosely on the wrist (Figure 2.Q). We utilized these constraints to enable interesting manipulation interactions like moving the bangle across the lower arm. Furthermore, the visibility of cylindrical ornaments from all directions led to a set of input methods we discuss later.

Head. This category of jewelry includes crowns, tiaras, chaplets, fillets and forehead ornaments. We explored *Maang Tikka*, an ornament wore on the forehead (Figure 2.R). It has a frontal form similar to a pendant.

4 DESIGNING JEWELRY-ENABLED TOUCH INTERACTION

Our study of structural elements and on-body location of jewelry inspired, at least, a variety of touch and manipulation interactions. In this and next section, we present those interactions through a set of artifacts meticulously chosen from the sample set to represent a rich space of interactions. For each of the artifacts, we present the interactions, the sensing technique prototyped, and a broader reflection on the opportunities of that augmentation. At times, we present tweaks (like adding a new jewelement or changing the arrangement of existing jewelements) we made to the artifacts to support a broader range of gestures.

Augmenting a grape necklace

We begin with a grape shaped necklace consisting of six circular plates (diameter 3.5 cm), a U-shaped element (length 8.7cm), all made in metal, integrated through 11 jump rings (Figure 3.A). Observing the distinctive, frontal form of the circular plates, we instrumented each of them as a separate touch point for fingers. The U-shaped element along with the chain assemblies facilitated the necklace to be worn around the neck. Observing its thin, continuous shape, we explored linear slide gestures over it, wherein the user moves his/her finger across its length (Figure 3.B).

Method. To instrument the necklace for touch input, we used capacitive sensing techniques [42]. A thin wire was soldered behind every circular plate and the capacitance drop (caused by the touch event) was sensed using a Teensy 3.1 microcontroller. To convert each plate into a separate electrode, we removed the metallic jump rings and tied the necklace back together using a thread — such that the elements didn't touch each other. Next, to convert the U-shaped element into a touch slider, we utilized a two electrode pattern shown in figure 3.C. The pattern was cut on copper tape and was pasted onto the plate after adding a layer of paper tape to insulate the electrodes from the jewelry material. The difference between the values observed for the two electrodes was used to sense the position of the finger on the plate.

Reflection. The touch interactions explored above are inspired by the shape and size of the discrete elements (e.g., circular plates) and the overall frontal form of the necklace. We explore these ideas further in the next exploration.

Spatial gestures on cabochon stones

Next we chose a necklace consisting of textured cabochon stones and golden-colored, conical plastic beads (Figure 3.D). We found the smooth, curved surface of the cabochon stone to offer expansive area (~15 cm sq.) for spatial touch interaction. We instrumented it to detect finger position along two perpendicular axis, similar to a touch digitizer on a smartphone. Apart from 2D tracking, we explored linear slide gestures along the edges of the stone (Figure 3.E).

Method. We instrumented cabochon stones using a double layer grid electrode arrangement [9]. Unlike previous case, no insulation was required here due to the non-conductive nature of jewel's material.

Reflection. Like in previous case, the shape and size of the cabochon stones motivated these interactions. The first interaction utilizes the area offered by a stone. The second one, on contrary, derives from its trapezoidal shape. Expanding this idea to the grape necklace, we explored *circular swipes* along the edges of a circular plate (Figure 3.F).

Figure 3: Exploring jewelry-enabled touch gestures

From jewelement to the jewelry

Another type of touch interaction that we observed with these necklaces was motivated by their overall shape — rather than the properties of discrete elements. For the grape necklace, we explored linear slide along the shape of the grape pattern, starting from the U-shaped element to the bottom most grape (3.G). For the necklace consisting of cabochon stones, a slide across the bulk of the necklace *round the neck* was augmented (3.H).

Reflection. Unlike previous cases, in these gestures, the interaction is performed not with the discrete jewelements, but with the artifact as a whole. Multiple points can be noted about these gestures. Firstly, the user can use her hand (rather than a finger) to perform these gestures due to the larger interaction space offered by the jewelry. Secondly, the shape of the individual jewelements (the stones or circular plates) holds less significance now. Thirdly, in the second gesture, the anatomy of the body (i.e. the shape of the neck) manifests itself in the interaction through the jewelry artifact.

Touch interaction with earrings

Along with the necklaces, we did several explorations with earrings. In one effort, we instrumented a stud earring to pickup touch events. For a jacket earring, we were able to sense touch events independently on both sides of the lobe. This allowed us to augment the gesture of pressing the lobe between a finger and the thumb (Figure 3.I). In another effort, we instrumented three earrings to pickup touch events and arranged them along the shape of the ear, as shown in (Figure 3.J). This enabled us to augment the gesture of a user sliding his/her finger around the ear (see figure). Finally, for the lizard-shaped earring (Figure 3.K), we explored a linear slide gesture along the trunk of the lizard.

Method. We implemented these gestures using the same capacitive sensing methods that we described for necklaces. To turn a metallic earring into an effective electrode, to sense touch events caused by finger(s), we had to insulate it from the ear. We did this by replacing its metallic ear-post with a plastic one. In all of these efforts, sensor wires were taken down the neck, behind the shoulder, where the micro controller was positioned.

Reflection. There are two points to note for the interaction with the lizard-shaped earring. Firstly, as a drop earring the artifact has a *three-dimensional* form. This makes the linear slide interaction to be different from that on a frontal piece, say the conical bead in the cabochon stone necklace (Figure 3.D). Unlike the conical bead that rests on the chest, the lizard needs to be supported from the other side to perform the gesture. Secondly, note how for the shape of the earring, the protrusions pertaining to the limbs of the lizard can be ignored, approximating its shape for the linear slide gesture.

Proximity-based interaction around the jewelry

Along with touch interaction, we also explored proximity-based interaction around the jewelry. In one effort, we explored in-air slide gestures close to an earring (Figure 3.L) and hover gestures over a wrist-worn bracelet (Figure 3.M). In another effort, we explored on-skin touch interaction round the neck (Figure 3.N) close to a necklace that was instrumented to pick up the gestures.

Method. The drop earring consisted of a perforated metal plate (length 7 cm) and *swivel* mounted beads. The drilled patterns on the plate allowed for passage of light — which was blocked by a finger close to the plate. We mounted five light-dependent resistor (LDR) sensors along the length of the plate (Figure 3.O), on its rear side to sense the finger and hence recognize the slide gestures. We used the same setup to detect hover gestures over the bracelet. To instrument the necklace, we mounted 9 LDR sensors behind it.

Reflection. We used the same setup to sense the interaction around the ear and on the wrist. We removed the ear-wire, the beads from the plate and added two chain assemblies and a clasp to wear it on the wrist. Note how the team was able to freely experiment with jewelry, combining elements to create new artifacts.

Interaction inspired by visual patterns

Another set of explorations that we did were with the visual patterns on jewelry artifacts. For the earring shown in figure 3.P, we converted the six regions in different color into six separate touch points. The necklace shown in figure 3.Q consists of four metal plates whose lengths decrease in a progression. Observing this pattern, we instrumented the necklace to detect top-to-down slide gestures.

Method. In both these efforts, capacitive sensing techniques described above were used to instrument the ornaments. Going with the thread material in the earring, we used conductive thread rather than copper tape to make the electrodes.

Reflection. We found it interesting how the visual design, the patterns on jewelry ornaments could inspire touch gestures. Experimenting this idea further, we started to *add* design patterns onto the jewels. For the cabochon stones, the arrows indicate the direction of slide gestures registered by each stone (see figure 3.R). We used small seed beads to design the patterns.

5 DESIGNING JEWELRY MANIPULATION INTERACTION

While touch interactions exploit availability of a surface, physical manipulation interactions are based on the element of motion that the jewels enable owing to the assembly of jewelements or their dynamic interactions with the body.

"Lifting" and moving jewelry

As in case of touch interaction, our exploration began with the grape necklace, through which we explored the gesture shown in figure 4.A. The necklace is raised above the chest, pulled against the neck, and is moved between the chest and the chin in a rotational trajectory — utilizing neck as the *hinge*. Next, we explored similar motion gestures with earrings. We started with a hoop earring worn onto the ear through an ear-post. Figure 4.B-C show the two gestures that we explored. Then we considered the drop earring shown in figure 4.D. The earring had a flexible structure. This allowed us to grasp the hanging end of the earring and move it in the 3D space (Figure 4.E) — as in case of slack offered by a chain.

Method. For the grape necklace and the hoop earring, we used a 6-axis MPU6050 accelerometer gyroscope module to sense the motion gestures (Figure 4.F). For the drop earring, we sensed the translation of the hanging end in two dimensions by utilizing computer vision based color-tracking techniques.

Reflection. For the first gesture, note that there are many ways of moving a necklace once raised above the chest. We chose the particular motion trajectory because it can enable precise control of a variable over a range of values — as the necklace is translated between the chest to the chin. For the interaction with the earrings, notice how the motion gestures are enabled by different properties of the jewelement, jewelry and the ear. The first one is enabled by the flexibility of the ear lobe; the second one is due to the assembly of the ear-post into the piercing; the third one (drop earring interaction) utilizes the flexible structure of the earring additionally.

Manipulating a pendant necklace

This set of exploration was done with a pendant necklace shown in the figure 4.G. It consisted of a square, ring-shaped pendant, a long chain assembly, and a circular bail to integrate the two components together. In one effort, we explored the *curling* of the chain around the finger to form loops around the finger (Figure 4.H). In another effort, we augmented the action of moving the pendant across the length of the chain. The chain is clutched with one hand, raised above the chest, and is pulled against the neck to form a "V". The pendant is held in the other hand and is moved along the chain (Figure 4.I). In a third effort, expanding on the action of raising the necklace discussed above, we explored the action shown in figure 4.J. Along with the neck, the finger is used as a second hinge, to perform two simultaneous rotational trajectories. Similarly, to expand upon the point three-dimensional translation action performed with the drop earring, we explored a two-point variation shown in figure 4.K, wherein we hold two points on the chain and translate them in the 3D space. Finally, inspired by the action of manipulating a clasp to hold (wear), release (remove) the necklace, we instrumented a *multi-strand* clasp to sense among the different points where the connection can be made by the user (Figure 4.L).

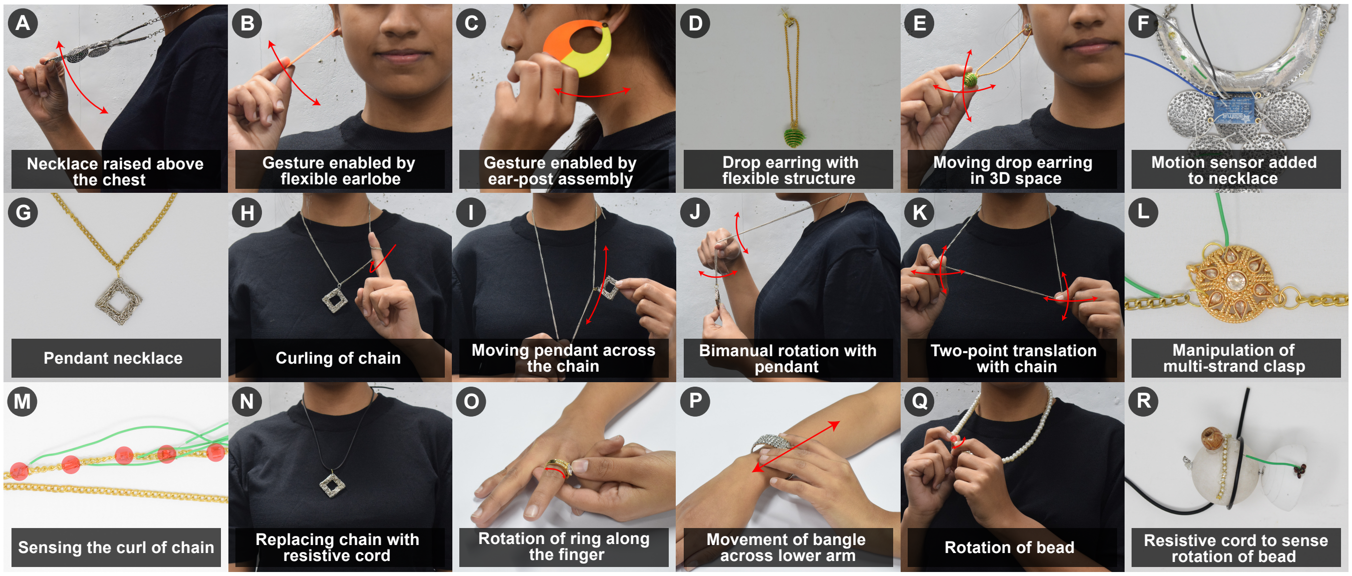

Figure 4: Exploring jewelry manipulation gestures

Method. To sense the curling of the chain, we implemented copper tape electrodes at equal intervals (1.5 cm) across the chain length (Figure 4.M). By observing the number of electrodes that registered finger-touch, we estimated the length of chain in contact with the finger and hence the extent of curling. To sense the position of the pendant over the chain, we used ten resistors and tied their ends to the chain — and to each other. By passing a small current through the network and measuring the voltage at the pendant, we were able to sense the position in 11 discrete steps, using theory of potential dividers. To replace the resistors, to sense pendant motion in a continuous manner, we hung the pendant over a length of resistive rubber cord [17] and wore it as a necklace (Figure 4.N). For the third and fourth gestures (Figure 4.J-K), we built on the inertial sensing, computer vision methods described previously for their variations. Finally, we instrumented the multi-strand clasp using resistive potential divider technique described for pendant motion (Figure 4.L).

Reflection. As in case of the grape necklace, we explored particular methods of manipulating the jewelry for the first four gestures (Figure 4.H-K). Notice how the flexibility of the chain, the assembly of the bail/pendant around it, the arrangement of chain between the neck and the two hands, together define these very nuanced interaction methods. Most existing wearable interactions utilize one or both hands. In the jewelry manipulation gestures that we explored, other body parts like the neck, chest or the chin also become significant along with the hands. For instance, by raising the neck and looking upward, the range of grape necklaces' rotation (between the chest and the chin) can be increased.

Manipulating cylindrical jewelry and beads

The first set of explorations here were done with artifacts of cylindrical form: a finger ring and a bangle. We explored two gestures: rotating a ring along the axis of the finger and moving a bangle up and down the lower arm (Figure 4.O-P). Secondly, we explored the action of rotating a bead (Fig. 4.Q).

Method. In the first two gestures, we utilized the inertial sensing approaches on original jewelry. In order to prototype the third one, we designed our own jewelry. Figure (Figure 4.R) shows two table-tennis balls visualized as beads, the resistive rubber cord wound around the left one. We utilized resistive potential divider technique to sense the rotation of the left ball in related to the right one (or vice versa).

Reflection. For the first two gestures, the sizing of the ornaments in relation to their respective body part (that facilitates the act of wearing them) enables the interaction. A bangle is worn through the hand and sits loosely on the wrist — and hence allows motion. A finger ring can be moved (in a limited context) after being worn on the proximal segment of the finger. As in case of manipulation gestures discussed before, a variety of motion gestures can be imagined.

6 DISCUSSION

Through *Gehna*, we hope to enable researchers and jewelry designers to explore a new form of digital jewelry [29] that

Ref.	Gestures	Properties that enable the gesture	Dimensionality
A	Touch points on grape necklace	size, shape of plates	event
B	Linear slide across U-shaped element	shape of element	1D
C	Two-dimensional tracking on cabochon stone	shape of cabochon stones	2D
D	Circular swipe across edge of plate	shape of plate	1D
E	Linear slide across edge of cabochone stone	shape of cabochon stones	1D
F	Linear slide across shape of grape pattern	shape of necklace	1D
G	Slide on necklace round the neck	shape of necklace; shape of neck	1D
H	Touch along shape of ear	shape of ear	1D
I	In-air slide close to earring	shape of earing	1D
J	Hover over wrist-worn bracelet	shape of bracelet	1D
K	On-skin touch round the neck	shape of neck	1D
L	Rotation manipulation with a necklace	shape of necklace; anatomy of neck	1D
M	Bimanual rotation with a pendant necklace	flexibility of chain; shape of necklace; anatomy of neck	1D + 1D
N	Earring rotation by ear-post assembly	assembly of ear post in earlobe	1D
O	Earring rotation by flexible earlobe	flexibility of earlobe	1D
P	Moving drop earring in 3D space	flexibility of chain	3D
Q	Two-point translation with chain	flexibility of chain	3D + 3D
R	Curing of chain	flexibility of chain	1D
S	Moving pendant across the chain	flexibility of chain; shape of necklace; anatomy of neck	1D
T	Manipulation of multi-strand clasp	Form of clasp	event
U	Movement of bangle across lower arm	cylindrical form of bangle; anatomy of arm	1D
V	Rotation of ring along the finger	cylindrical form of ring; anatomy of finger	1D

Jewelement related property Jewelry related property Body related property

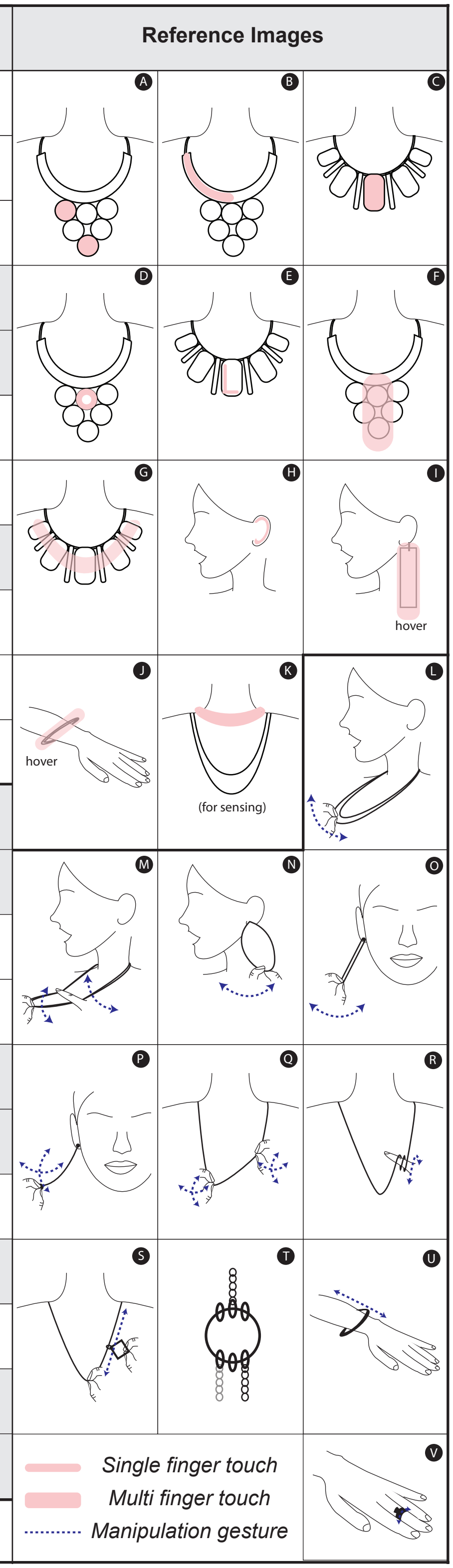

Figure 5: Jewelry-enabled gestures

can inspire a variety of interaction techniques. There are three primary implications of our work.

First, the taxonomy of jewelry design can fill in the void regarding jewelry-related knowledge within the community, which in its current state is limited to commonly heard items such as rings and necklaces. Description of jewelements and body-related design factors can serve as the common language to facilitate discussion. Second, our sample artifacts, the speculative applications, can serve as design inspiration, similar to the idea of "artifact" as described by Zimmerman et al. while defining RtD [53]. Other designers can refer to them while considering the jewelry artifacts in their particular geographical location or cultural setting. Importantly, figure 5 can serve as a quick reference for the practitioners looking to incorporate these gestures into their applications. Third, our work can both inspire as well as benefit from the research on smart materials [4] which can address implementation challenges, while opening new avenues of interactions. The first point is heavily supported through earlier text. Therefore, below we only support the last two points.

Jewelry-Enabled Gestures

Figure 5 provides an overview of all gestures that we have explored. While some interactions are enabled by the properties of jewelements, others are based in affordances of the jewelry artifact as a whole. Similarly, other gestures depend upon how the artifact is worn on the body. The third column of the table captures this information. It can be observed that many of the gestures are enabled by a combination of jewelement, jewelry or body related factors. *Dimensionality* defines how a gesture can be used. As defined by Hinckley et al. in the literature on input techniques [15], gestures having a dimensionality of *1D* or *2D* can be used to control *1* and *2* variables respectively. For instance, 2D tracking on a cabochon stone can be used to control two variables like a trackpad. Finally some gestures are events and can be used to detect a state change like a *mouse click*. This information is captured in the fourth column of the table.

Potential Applications

Below we present three speculative applications that give a glimpse of the versatility of jewelry as an input modality.

Going beyond touchscreens. We see a huge potential for using jewelry-based input techniques for always-available, eyes-free interaction with wearable devices and alternative input to GUI. For instance, one can access a trackpad-like 2D input by manipulating the earring gesture (Figure 5.P). A bead jewelement on the earring can provide a touch or mouse click event (similar to the grape necklace in figure 5.A).

Mood journaling for a happier self. Digital self-tracking technologies have been observed to offer many benefits, can help an individual to become "*fitter, happier, and more productive*" [10]. In this space, a user may use a necklace to journal her mood in a timely yet subtle manner. The artifact will comprise of two round-shaped beads, both augmented as touch points. A bead in blue color, having a smooth texture, can represent calmness; the second one in brown color, having a rough texture to represent agitation. The user finds the appropriate bead using her tactile senses and holds it for a few moments to register her mood. Her responses get stored onto a smartphone application for self-reflection. Similar opportunities exist for conducting microinteractions-based ecological momentary assessments [19].

Want to enjoy my picnic! Say you want to receive the usual buzzing (associated with notifications and alerts) while in office but don't want to be disturbed when out for a picnic with family. This application is enabled by the manipulation of the multi-strand clasp (Figure 5.T) that is instrumented to sense among the different points where the connection is made (Figure 4.L). User's choice of a connection point represents a conscious decision that she takes every morning while wearing the jewelry. She uses the default connection point on a working day but wears the ornament differently when she is on a leave. Her smartphone adjusts her schedule according to her plans.

Leveraging Smart Materials for Sensing

An important part of our exploration was to instrument the jewelry artifacts using suitable approaches from DIY electronics to enable the interactions. While doing this, we observed an interesting opportunity to explore a synergy between jewelry materials and the sensing methods. A compelling possibility within that direction is to replace the material of traditional jewelry with smarter ones to enable sensing ([4],) while preserving the aesthetic qualities. One example that we explored was to replace the thread in the earring (shown in figure 3.P) with conductive yarn to enable capacitive touch sensing. Similarly, we replaced the chain of a pendant necklace with a resistive rubber cord (see figure 4.N), allowing us to sense the pendant manipulation gesture. Future advancements in smart material composites can lead to more such solutions.

7 CONCLUSION

In this work, we have explored jewelry as an input modality. By using the Research through Design (RtD) method, we designed a rich set of interactions with jewels based on their physical affordances, the place of wearing on the body. By borrowing perspectives from fields of jewelry design, input techniques and wearable computing, we have compiled this manuscript that can enable researchers and jewelry designers to explore this new form of input.

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