*Note:* Page numbers followed by f indicate figures and t indicate tables.

A Acid-processing method, 25–26 Adhesive bonding, 145 ArmorLite <sup>TM</sup> , 7 As-spun fibers, 23–25 Asymmetric supercapacitor, 70 Atlas weave, 90, 91 <i>f</i> Autocatalytic plating process, 37 Automated grabbing systems, 148	CNT/CB coatings, 36–37 CNT synthesis, 55–56 CNT yarn core-spun yarn, 59–60 electrical conductivity, 63–64 flyer spinning, 57–58 rub densification, 59 sensors, 65 structures and formation, 61–62 supercapacitors, 66–70
B Bandgap energy, 157 Base-processing method, 25 Bedford cord, 11 Body-worn textile antenna, 225–227 Bulk CPYs conductive fillers, 32–36 hybrid polymer–metal yarns, 27–30 ICPs, 22, 23–27	tensile properties, 62 textiles, 64–65 up-spinning, 58–59 Commonwealth Scientific and Industrial Research Organisation (CSIRO), 57–58 Conductive fibres carbon nanotubes, 12–13 in extrusion, 13 future aspects, 14–15 metal fibres, 5
C Capacitance sensors, 85 Carbon FRP (CFRP) layers, 150 Carbon nanotubes (CNTs), 55 piezocomposites, 179	metallized fibres, 9–10 plastic strips, 10–11 polyaniline (PANI), 11 substrates and conductive elements, 6–7
yarns (see CNT yarn) Catalogue classification, textile-based sensors access characteristics, 84f benefits and conveniences, 82 classification and structure, 82–83 references, 81f, 83 solutions, 83, 84f usability, 83–84 Cellular communications, 225–227 Chainsaw protection trousers, 149 Chain-stitch embroidery (Ari), 91–93, 138, 138f Chemical polymerization, 44	Conductive fibre applications biomedical sensors, 13 e-broidery, 13 embroidery, 13 fabric electrodes, 13 piezoelectric fibre, 13 PPy-coated Lycra, 13 steel threads, 13 transducers, 13 Conductive fibre developments, 6 in eighteenth century, 4 in nineteenth century, 5 in twentieth century, 5 Conductive joints types, 146f
Chemical polymenzation, 44	Conductive Johns types, 1 roj

Conductive polymer yarns (CPYs)	losses, 208–211
bulk, 23–36	textile microstrip lines, 207–208
chemical polymerization, 44	conformal applications, 227
dipping-and-drying technique, 44	future aspects, 234–236
electrospinning technique, 42–43	GSM/PCS/WLAN communications,
fiber drawing technique, 43–44	221–227
melt spinning technique, 41–42	insertion loss
surface, 36–40	E-fiber textile surface, 214–216
Conductive textiles, 202–203, 203 <i>f</i>	fiber density, 213–214
embroidery process, 204–205	stitching density, 211–213
losses, 207–211	polymer substrates, 205–207
polymer substrates, 205–207	RF performance
radio frequency losses, 207–211	textile antenna array, 216–219
threads, 203	textile patch antenna, 216
	RF textile sensor, 228–230
Cross-polarized radiation, 224–225	threads, 203
_	tire tracking applications, 230–233
D	UHF communications, 219–221
DARPA (Defence Advanced Research	wearable RF electronics, 201–202, 202f
Projects Agency) funding, 246	
Dipping-and-drying technique, 44	Embroidery
Distributed fibre optic sensors	advantages, 141 chain-stitch embroidery (Ari), 91–93,
intrinsic, 283–285	138, 138 <i>f</i>
quasi, 285	embroidery hoop dimensions, 142
Dodecylbenzenesulfonic acid (DBSA), 35	joining technology, 140–141
Double lock stitch, 94, 95 <i>f</i> , 139 <i>f</i> .	kinds, 90–91
See also Standard embroidery	
technique	manufacturing of, 139–140
Drawability of CNT forests, 56-57	moss embroidery principle, 91–93, 92f
2D weaving	paths and circuit board (PCB), 144, 144
atlas weave, 90, 91f	standard embroidery technique, 93–94,
plain weave, 89–90, 91f	95f, 138, 139f
stages, 89f	tailored fibre placement (TFP),
warp and weft yarns, 89, 90f	94–95, 139
Dye-sensitised solar cells (DSSCs), 160	technical challenges, 142–144
	tubular embroidery machine, 92f, 143f
E	Embroidery hoop dimensions, 142
	Emeraldine base (EB), 23
ECG/EMG monitoring systems, 259–260	Encapsulated Chip Area (ECA), 112 Encapsulation technique
E-fiber textile surface, 214–216	•
Electrical conductivity, 63–64	resin impregnated ECA process,
Electrocardiogram (ECG), 258, 259–260	113–115
Electromyogram (EMG), 258, 259–260	side-by-side thermal bonding
Electronically active textiles (EATs), 110	process, 113
Electronically functional yarn (EFY),	Environmental sensing, military textiles,
112, 115 <i>f</i>	240–242
Electrospinning technique, 42–43, 180	early warning systems, 245
Embroidered textile antennas	health monitoring, 242–245 Epoxy-based conductive adhesives, 146
conductive textiles, 202–203, 203 <i>f</i> , 204–205	E-Thread <sup>r</sup> , 110–111
40 <del>4</del> -403	L-1111Cau, 110—111

F	cross-polarized radiation, 224–225
FabRoc® yarn, 12, 121–123	multiband antenna design, 221-223
Ferroelectric materials, 173	radiation pattern, 224
Fiber density, 213–214	resonance frequency, detuning, 224
Fiber drawing technique, 43–44	
Fibre Bragg gratings (FBGs) sensors,	Н
286–287	Heating theory, 119–120
Fibre-coated sensors, 102–103	Health monitoring
Fibre electronics technology, 109, 111–115	electrophysiological signals, 243–244
Fibre-reinforced polymers (FRPs), 288	Sensatext, 244
Fibres, textile-based sensors, 78	SmartLife Technology, 244
Flyer spinning, 57–58	sweat sensors, 244, 244f
Tijer spinning, 37 30	weaving and knitting processes,
	245
G	= :=
Geotechnical and civil engineering	Humidity and moisture monitoring, textile-based sensors, 96–100
extrinsic optical fibre sensors, 281–282	
fibre Bragg gratings sensors, 286–287	Hybrid polymer–metal yarns fiber drawing techniques, 30–31
field trials and on-site tests	metal-core yarns, 27–30, 27f, 28t
of railroad, Chemnitz (Germany), 294	polymer-core yarns, 27 <i>f</i> , 28 <i>t</i> , 30
of slope failure, Zimmersrode	polymer–metal braided yarns, 27f,
(Germany), 295–297	
slope stability, Belchatow (Poland),	28t, 30
294–295	т
geotextiles, 280, 281f	I
intensity-based fibre optical sensors, 282	ICP coatings, 37–38
intrinsic distributed fibre optic sensors,	Intelligent Knee Sleeve (IKS), 265–266, 266f
281–282, 283–285	Intelligent Textiles, 173, 242–243, 242 <i>f</i>
non-crimp fabrics, 276–277	piezoelectric phenomenon
phase-modulated fibre optical sensors, 282	(see Piezoelectric energy)
polarisation-modulated fibre optical	PV (see Photovoltaic (PV) energy)
sensors, 283	Intensity-based fibre optical sensors, 282
polymer optical fibre sensors, 285–286	Intrinsically conductive polymers (ICPs),
retrofit strategy	33–36
full-coverage strategies, 276–277	PANI fibers, 23–26
reinforcing strips, 276–277	PPy fibers, 26–27
seismic reinforcement, masonry buildings	IR-CNT yarn, 66–68
at Eucentre (Italy), 291–292	Isotropic conductive adhesive (ICA),
at IIT (India), 293–294	145, 147
sensing capability, 281	
wavelength-modulated fibre optical	J
sensors, 283	Joining technology
standardisation needs, 297–299	adhesive bonding, 145
Glass FRP (GFRP) layers, 150	automated grabbing systems, 148
Global Systemfor Mobile Communications	carbon FRP (CFRP) layers, 150
(GSM), 221–223	chainsaw protection trousers, 149
Glueing, 148	conductive joints types, 146f
GSM/PCS/WLAN communications	continuous manufacturing, 135
cellular communications, 225–227	conventional textiles, 134–135

Joining technology (Continued)	PCNs, 246
embroidery, 138–139.	position detection, 248
(see also Embroidery)	sensors, 240–242, 241 <i>t</i>
epoxy-based conductive adhesives, 146	tactile comfort, 252
glass FRP (GFRP) layers, 150	textile antennae, 246
glueing, 148	thermal comfort, 252
isotropic conductive adhesive (ICA),	thermal regulation, 247–248
145, 147	WAN systems, 246
LEDs, automated attachment, 136f	with wearable computer and keyboard,
non-conductive adhesive (NCA) bonding	242–243, 242 <i>f</i>
solutions, 135, 145–146	Military wireless uses, piezoelectric energy,
positioning, 134f	190–191
SensFloor <sup>r</sup> system modules, 137 <i>f</i>	Moss embroidery principle, 91–93, 92f
standard adhesive application method, 148	Motion sensors
strategies and automatic approaches,	accelerometer, 261, 262t
145–148	strain sensors, 262, 263f
by textile processing, 137–144	Multiband antenna design, 221–223
textile ribbon cables and connexion	Multifunctional geotextiles (MFGs), 280, 281f
elements, 136f	Trializational government (Fig. 35), 200, 201,
elements, 15 og	N
K	
	Nanofibres/yarns, piezo fibres
Knitting process, 123–125	manufacturing technique, 180
_	Nanowires, piezocomposites, 179
L	N-methyl-2-pyrrolidone (NMP), 23
LifeShirt <sup>®</sup> , 260, 263–264, 264 <i>f</i>	N,N'-dimethylpropylene urea (DMPU), 23
Light-emitting diode (LED), 11	Non-conductive adhesive (NCA) bonding
automated attachment, 136f	solutions, 135, 145–146
Low-density polyethylene (LDPE), 31	Non-crimp fabrics
	advantages, 277
M	biaxial structure, 277, 278f
Medical uses, piezoelectric energy, 190–191	characteristics, 276–277
Melt spinning technique, 41–42	embedded fibre optic sensors,
Metal-based textile heaters, 118, 119f,	277–280, 279 <i>f</i>
120–121	mechanical properties, 276–277
Metallic coatings, 36–37	quadriaxial hybrid fabric, 277, 278f
miCoach <sup>TM</sup> , 266–267, 267 <i>f</i>	quality check, 280, 280f
Military textiles, 240 <i>t</i>	SENTEX 8300, 277–280, 279f
armoured vehicles, 248–249	triaxial structure, 277, 278f
	Nuclear, biological and chemical (NBC)
camouflage uniforms, 247 design difficulties, 249–250	attacks, 245
energy scavenging devices, 251	
early warning systems, 245	0
	Optical time-domain reflectometry (OTDR)
environmental sensing, 240–242	principle, 283–284, 285–286, 290
future aspects, 253–254	
health monitoring, 242–245	P
information systems, 246	
maintenance, 252–253	PANI fibers
mobility, 252	acid-processing method, 25–26

C1 22.25	Pi de
as-spun fibers, 23–25	Piezoelectric sensor, 261
base-processing method, 25	Piezo fabrics
DBSA, 35	electro-spinning, 180
emeraldine base, 23	energy harvesting testing, 187–188
solution-spinning process, 23	fibres manufacturing, 180–181
wet-spinning method, 26	melt spinning, 181
Paths and circuit board (PCB), 144, 144 <i>f</i>	nanofibres/yarns, 180
PEDOT:PSS, 159f, 161	types, manufacturing techniques, 183–185
Personal Communications Service (PCS),	wrapping/twisting, 180
221–223	Piezo fibres manufacturing technique, 181
Phase-modulated fibre optical sensors, 282	Piezopolymers, 178
Phenyl-C61-butyric acid methyl ester	fibres manufacturing, 182
(PCBM), 158–160, 159f	Piezoresistive sensors, 13, 260
Photovoltaic (PV) energy	Plain weave, 89–90, 91 <i>f</i>
advantages and requirements, flexible	Polarisation-modulated fibre optical
substrates, 160–161	sensors, 283
applications, 167–168	Polyaniline (PANI), 11
cells operation mechanism, 156–157	Polyethylene terephthalate (PET) fibres, 164
electrical conductive textiles, 165–166	Poly-3-hexyl thiophene (P3HT),
fabrics manufacture, 166–167	158–160, 159 <i>f</i>
solar textile fabrics construction, 161–163	Polymer-based textile heaters, 118, 119f
technological specifications, 166	conductive yarn, 126–127
textiles requirements, 163–165	design, 125–126
types, 157–160	FabRoc yarn, 121–123
Piezoceramic fibres manufacturing, 181	heated fabrics, 129–130
Piezocomposites	heated gloves, 129
carbon nanotubes, 179	knitting process, 123–125
copolymers, 179	power supply system, 127–128
fibres manufacturing, 182–183	processing techniques, 128
nanowires, 179	Polymer optical fibre (POF) sensors, 285–286
Piezoelectric energy	Polymer yarns, conductive fillers
applications, 188–191	CB-filled polymer yarns, 32–33
charge formation and poling, 175	CNT-filled polymer yarns, 33, 34t
direct and converse effects, 176	ICPs, 33–36
energy requirements, 188	POLYTECT project, 287–291
history of, 174–175	PPy-coated Lycra, 13
human-powered wearable devices	Pressure-mapping systems, textile-based
feasibility, 188–189	sensors, 100–102
manufacturing of, 179–188	Printed circuit board (PCB), 7, 110
materials in, 173	Printed sensors, 103
mechanical energy conversion, 176–178	Pseudocapacitance, 66–68
medical and military wireless uses, 190–191	PVDF copolymers, 179
piezoceramics, 178, 181	
piezocomposites, 178–179, 182–183	R
piezo fabrics, 180–181, 183–185	
piezopolymers, 178, 182	Radiation pattern, 224
principles, 175–176	Radio frequency identification (RFID),
wearable energy harvesting, fabrication	110–111, 201
optimisation, 185–186	References, 81f, 83

Resin impregnated ECA process	Supercapacitors
fibre bonding, 113f	asymmetric, 70
light-emitting yarn, 115, 115f	core-spun yarn, 70
micro-pod, 114	IR-CNT yarn, 66-68
objectives, 113-114	as substrate, 68–69
polymer resin, 113	Surface CPYs, 36–40
RFID chips, 114	CNT/CB coatings, 36–37
temperature-sensing yarn, 115	ICPs coatings, 37–38
Resonance frequency, detuning, 224	metallic coatings, 36–37
Respiratory inductive plethysmography (RIP), 260, 260 <i>f</i>	Surface mount devices (SMD), 111
Respiratory sensors	
capacitive displacement sensors, 261	T
piezoelectric sensor, 261	Tailored fibre placement (TFP), 94-95, 139
piezoresistive sensor, 260	Temperature sensors, 86–89
respiratory inductive plethysmography,	TenCate GeoDetect® System, 290–291
260, 260 <i>f</i>	Textile antenna array, 216–219
RFID devices, 14	Textile-based sensors
Rub densification, 59	applications, 95–102
	capacitance sensors, 85
	catalogue classification, 82–84
S	definition, 76
SensFloor <sup>r</sup> system modules, 137f	development of, methodical approach to,
Sensor-based monitoring systems,	78–84
80f, 81	2D weaving, 89–90
Sensors, 65	embroidering, 90–95
SENTEX 410, 289–290, 290f	fibre(s), 78
Shieldex®, 9	fibre-coated sensors, 102–103
Silver-coated Amberstrand® fibers, 203	in humidity and moisture monitoring,
Small electronic device (SEW), 265	96–100
Smart 7-step tool	integration levels, 75, 76f
data analysis and evaluation, 81	manufacturing technologies, 89–95
limit value, 81	in pressure-mapping systems, 100–102
material and energy flow, 79-80	printed sensors, 103
performance test, connecting electronic	production methods, 77f
components, 80–81	smart 7-step tool, 79–81
physical parameters and measuring	structure levels, 77f
technique, 80	in supporting textile, 77f
requirements, 79	temperature sensors, 86–89
textile prototype manufacture, 80	two- or three-dimensional textiles, 78
Smart textiles	types, 85–89
described, 75	uses, 75
intelligence for textiles hierarchy, 97t	variations, 76–77
Sozni stitch, 93	yarns, 78
Standard adhesive application method, 148	Textile fabrics
Standard embroidery technique, 93–94, 95 <i>f</i> ,	fibre electronics technology, 109, 111-115
138, 139 <i>f</i>	knitted structure, 109, 110f
Steaming, 128	state of the art, 110–111
Stitching density, 211–213	woven structure, 109, 110f

Textile heating systems advantage, 257 future aspects, 130-131 ECG/EMG monitoring sensors, 259-260 heating theory, 119-120 IKS, 265-266, 266f metal-based, 118, 119f, 120-121 implantable sensing technology, 268f, 268t, 269 performance-driven functionality, 117 LifeShirt®, 263–264, 264f polymer-based, 118, 119f miCoach<sup>TM</sup>, 266-267, 267f warmth conditions, 117 Textile microstrip lines, 207-208 motion sensors, 261-262 Textile patch antenna, 216 portable technologies, 268–269, 268f, 268t Textile ribbon cables and connexion respiratory sensors, 260-261 schematic structure, 257, 258f elements, 136f Tire tracking applications, 230–233 sensor module product specifications, 258t Transducers, 13 wearable sensor module, 268-269, Tubular embroidery machine, 92f, 143f 268f, 268t Two- or three-dimensional textiles, 78 WWS, 264-265, 265f Wearable Wellness System (WWS), U 264–265, 265*f* UHF body-worn communications, 219-221 Wet-spinning method, 26 Wireless Local Area Network (WLAN), Ultra-high frequency (UHF), 219 221-223  $\mathbf{W}$ Wrapping/twisting, 180 Wavelength-modulated fibre optical sensors, 283 Y Wearable energy harvesting, fabrication optimisation, 185-186 Yarns Wearable health monitoring systems, textile-based sensors, 78 athletes warp and weft, 89, 90f